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ANNUAL REPORT ON ELECTRONICS RESEARCH AT THE UNIVERSITY OF TEXA--ETC(U)
SEP 78 E J POWERS F49620-77-C-0101

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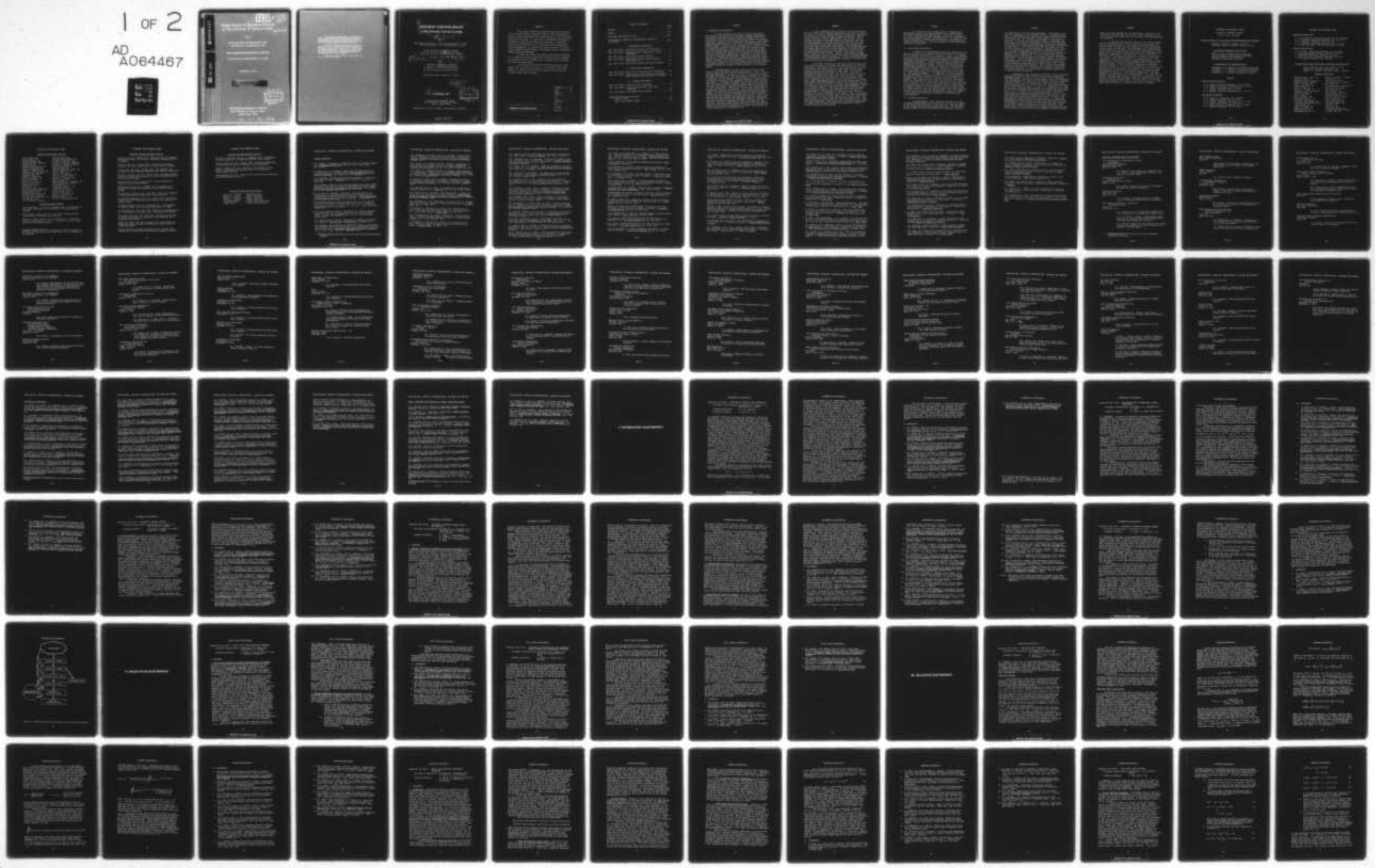

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Annual Report on Electronics Research at The University of Texas at Austin

A042406

No. 25

For the period April 1, 1977 through March 31, 1978

(Also including April 1, 1978 through August 31, 1978)

JOINT SERVICES ELECTRONICS PROGRAM

Research Contract AFOSR F49620-77-C-0101

September 15, 1978

ELECTRONICS RESEARCH CENTER
The University of Texas at Austin
Austin, Texas 78712

The Electronics Research Center at The University of Texas at Austin consists of interdisciplinary laboratories in which graduate faculty members and graduate candidates from numerous academic disciplines conduct research. The disciplines represented in this report include information electronics, solid state electronics and quantum electronics.

The research summarized in this report was supported by the Department of Defense's JOINT SERVICES ELECTRONICS PROGRAM (U.S. Army, U.S. Navy, and the U.S. Air Force) through the Research Contract AFOSR F49620-77-C-0101. This program is monitored by the Department of Defense's JSEP Technical Advisory Committee consisting of representatives from the U.S. Army Research Office, Office of Naval Research and the U.S. Air Force Office of Scientific Research.

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9 Rept. for 1 Apr 77-31 Aug 78,

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Submitted by Edward J. Powers
on behalf of the faculty and staff
of the Electronics Research Center

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15 Sep~~tember 15, 19~~78

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ABSTRACT

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin and which were supported by the Joint Services Electronics Program. In the area of Information Electronics progress is reported for projects involving (1) nonlinear filtering and estimation, (2) electronic multi-dimensional signal processing, (3) electronic control systems, (4) electronic computer system design and analysis and (5) electronic computer software systems.

In the Solid State Electronics area recent findings in (1) basic solid state materials research and (2) research on instabilities and transport near surfaces and interfaces of solids are described.

In the area of Quantum Electronics progress is presented for the following projects: (1) nonlinear wave phenomena, (2) atomic and molecular electronic processes and (3) high power laser systems.

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SUMMARY

I. INFORMATION ELECTRONICS

In work devoted to *Nonlinear Filtering and Estimation*, the modeling and analysis of nonlinear systems described by differential equations driven by point process noise were considered, and the stochastic calculus of McShane was generalized to include such differential equations. A new method based upon characteristic functionals was presented for analyzing the moment stability of certain bilinear systems with random inputs. Recursive state estimators for certain classes of nonlinear systems in both continuous and discrete time have been derived and it was shown that the optimal estimators for systems described by certain Volterra series expansions or by bilinear systems with nilpotent Lie algebras are recursive and finite dimensional. Methods of Fourier analysis and an assumed folded normal density approximation were applied to a nonlinear estimation problem in which the observation consists of a doubly stochastic Poisson process and a particular application to optical phase tracking was presented. A localized version of the Kolmogorov-Smirnov statistic was given for detecting changes in the structure of a stochastic system.

Accomplishments in *Electronic Multi-dimensional Signal Processing* fall into the following three areas. First, the work on phase distortion due to filtering in digital pictures has been completed. In this research, a technique has been developed to calculate a measure of phase distortion. Second, a technique for the design of two-dimensional nonrecursive filters with nonrectangular impulse response arrays has been developed. In general, two-dimensional nonrecursive filters with rectangular impulse response arrays have the disadvantage that the filtering operation becomes slow as the size of the array increases. This difficulty has been alleviated to a large extent by the new method. Third, the design of two-dimensional recursive filters has been investigated extensively, and two more design techniques have been developed in addition to the previous technique, which is based upon rotating frequency responses of prototype filters. One of the new methods approximates nonseparable frequency characteristics by sums and products of separable transfer functions by shifting frequency responses of simple prototype filters. The other technique approximates arbitrary magnitude characteristics with semicausal recursive filters by utilizing the spectral factorization capability of planar least square inverse polynomials of semicausal form.

SUMMARY

In the research area of *Electronic Control Systems* sensitivity theory was studied theoretically and was utilized in the design of control systems which are relatively insensitive to variations in uncertain plant model parameters. The extended multiple shooting (EMS) method for solving linear elliptic boundary value problems was investigated, and the convergence speed of the EMS method was improved over that of other methods by requiring the solution of linear algebraic systems of much lower dimension. High-performance recursive state estimators were designed for systems evolving on compact manifold (such as the sphere), and these estimators performed as well or better than other known filters for many important problems. Optimal recursive state estimators were derived for other classes of nonlinear systems; these estimators represent some of the very few known examples of implementable optimal estimators. Levin's Loop Method for analyzing qualitative stability was extended to include transient and periodic disturbances.

The major objective of *Electronic Computer Systems Design and Analysis* has been to increase the capabilities of digital simulation; both simulation of a fault free network for logic verification and timing analysis, and simulation of faulty networks for the verification of test sets. Significant accomplishments have been made in two areas, in terms of approaching these objectives. The first of these is the development of practical techniques, with theoretical basis, for the automatic partitioning of a digital network into small combinational units which can be simulated at a higher level, <u>with the same accuracy</u> as would be accomplished at the gate level. The second area involves the development of algorithms and data structures to support <u>very accurate</u> modeling of functional units for non-fault and fault simulation; in a cost effective manner. This work utilized techniques known as concurrent simulation and represents new and original accomplishments, with respect to the accuracy and size of systems that can be modeled and simulated. This is of major importance with the increased use of LSI and VLSI technologies. In addition, the use of live, safe and persistent Petri nets in the design of digital systems has been investigated. Top down and bottom up techniques for the synthesis of Petri nets have been developed. This methodology is equally applicable to hardware and software systems and especially suited to systems exhibiting concurrency.

SUMMARY

In *Electronic Computer Software Systems* research has established a basis for the development of a comprehensive Data Base Systems design methodology. This work is unique in that it includes the whole process of design, from gathering requirements to physical implementation. Furthermore, the use of techniques from the uses of software engineering and computer based design in the establishment of the methodology, is of major importance.

II. SOLID STATE ELECTRONICS

A number of accomplishments have been achieved in our work on *Basic Solid State Materials Research* and *Research on Instabilities and Transport Near Surfaces and Interfaces of Solids*. For example, in our studies of solid state reactions at metal-semiconductor interfaces, we have made significant progress in understanding the basic mechanisms and physical structures involved in low temperature reactions. We have also developed a model hypothesis for how Schottky barrier heights are controlled by intermediate "membrane" phases. We have also characterized by TED measurements the structural formation of ultrathin films of several transition metals (Co, Ni, Pd and Pt) and correlated these with their surface resistivity for Co and Pt. The results suggest a two-dimensional nucleation model for the compound formation. In addition, we have developed interactive graphic software for use in the ellipsometric determination of the optical constants of thin films on substrates. This approach will allow for the rapid and convenient determination of the optical constants of any surface film. Finally, we have made some significant initial progress in understanding the role of electronic phase transitions in martensitic structural transformations using VO_2 thin films as a model system. We have induced a non-equilibrium state in these films in times less than 20 psec. Our time resolved reflectivity and absorption measurements indirectly support a soft phonon mode instability model of the martensitic transformation.

III. QUANTUM ELECTRONICS

Accomplishments in the *Nonlinear Wave Phenomena* unit included nonlinear optics work devoted to studying new types of molecular nonlinearities in the infrared. The saturation of the linear and nonlinear properties of SF_6 has now been observed under various conditions and an empirical model of

SUMMARY

SF_6 behavior at 10.6μ has been developed. Preliminary third harmonic generation data has been taken on a new system, NH_3 gas. An experimental and theoretical study of third harmonic generation in metal-dielectric wave-guides filled with CO was carried out. An enhanced third harmonic conversion was observed. In addition, progress was made in developing digital bispectral analysis techniques to analyze and interpret fluctuation data generated by nonlinear wave-wave interactions. In particular, it was demonstrated that the bispectrum and its derivatives (e.g., the bicoherence spectrum) may be used (1) to discriminate between nonlinearly coupled waves and statistically independent waves in a self-excited fluctuation spectrum (2) to measure the fraction of wave power due to quadratic wave coupling and (3) to experimentally determine the strength of the coupling coefficient from the raw fluctuation data. Practical aspects of digital bispectral analysis techniques, such as estimation and statistical variability of the estimator, have also been investigated. Work on modeling nonlinear wave phenomena in terms of nonlinear system transfer functions was initiated. The concept of the Wiener filter was extended to a quadratically nonlinear system and an analytic solution for the quadratic transfer function of a causal system was obtained.

Progress in *Atomic and Molecular Electronic Processes* includes the work concerning light scattering in highly polarizable, compressed gases (Ar, Kr, Xe, Ch_4), which is now completed. The experimental, collision-induced spectra could be reproduced from a wavemechanical theory in all details, and on an absolute intensity scale. It was learned that the anisotropy of the polarizability tensor of collisional, like pairs was dominated by the electrostatic term, $\gamma(r) = 6\alpha^2/r^3$. Corrections at close range, which were previously thought to be necessary on account of electronic exchange and overlap, were shown to be less than 4% at $r = \sigma$ (σ is the root of the pair potential function). Other spectra of weakly polarizable gases (Ne) are still inconsistent with theory, probably owing to impurities. A gas purifying system has been completed and will be used in the near future to record spectra of pure gases. In other work, experimental charge density distributions based on precision measurements of electron diffraction cross sections were used to calculate a set of moments for several molecules. These values were compared and agreed with results derived from optical data. This agreement is of notable significance since the diffraction work can be readily expanded to other systems

where all other methods are not applicable. Moments of the electronic distributions are, next to the total energy, the most commonly used quantities to critically evaluate numerical wavefunctions.

In the work dealing with *High Power Laser Systems* energy transfer processes that relate to several new gas laser systems are being studied. A large body of data has been collected during the past year on the kinetics of electron beam excited oxide gas systems. The experiments have concentrated on the production and decay of the $O(^1S_0)$ state which is the upper level for several potentially efficient high power laser amplifier transitions. Progress this year has identified efficient oxygen excitation channels in argon + NeO and argon + O_2 mixtures. Preliminary data on Ne-O_2 mixtures indicates that neon is much less efficient in generating $O(^1S_0)$. The completion of a gas purification system complemented the above measurements by eliminating interference due to impurity nitrogen ion bands. These successful measurement techniques will be extended to other promising systems in the future. In addition, we have initiated new work relating to optical components used in high power laser system. The grating rhomb beam sampling device for high average power lasers has been analyzed and optimized. The imaging properties of the beam sampler were analyzed for curved wavefronts. Not only was an optimal, minimum abberations, configuration determined, but an inverse algorithm was developed which can deconvolve the aberations in pre-existing data. This will be of use in high power propagation studies where accurate determination of the amplitude and phase of a sampled laser beam is needed.

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Advanced Degrees Awarded

Ajoy Kumar Bose, EE, Ph.D., December 1977, "Procedures for Functional Partitioning and Simulation of Large Digital Systems"

Hsien-Ching K. Chen, EE, M.S., May 1978, "Banyan Network Logic Design and Hardware Construction"

Charles F. Hart, Physics, M.A., August 1977, "A Spectral Study of the Emission of $O(^1S_0)$ in Mixtures of O_2 in Argon Excited by an Electron Beam"

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*Denotes students who have contributed to JSEP projects, but who have not been paid out of JSEP funds (e.g., students on fellowships).

PERSONNEL AND RESEARCH AREAS

Advanced Degrees Awarded (cont'd)

Kai Hsu, EE, M.S., August 1977, "The Evaluation of Several Suboptimal Filters for Bilinear Stochastic Systems Evolving on Spheres"

James Hu, EE, M.S., August 1978, "A Study of Silicides Formation for Thin Cobalt Film on Single Crystal Silicon"

Yu-Huei Jea, EE, Ph.D., August 1977, "The Analysis and Synthesis of Some Advanced Techniques for Digital Simulation"

Patrick G. Karger, EE, M.S., August 1978, "Automatic Modularization of Gate Level Networks to Facilitate Simulation of Large Digital Systems"

Young Kim, EE, Ph.D., August 1978, "Digital Bispectral Analysis and Its Applications"

Chang-Huan Liu, EE, M.S., August 1978, "A Comparison of Optimal and Suboptimal Estimators and Estimation Lower Bounds"

Bruce Miller, Physics, M.S., May 1978, "Scattering Geometry on Measured Electron Differential Cross-Sections"

Dariush Minoo-Hamedani, EE, M.S., August 1978, "Mean Square Prediction Using a Memoryless Nonlinearity Followed by a Linear Filter"

Ali-Akbar Mohseni, EE, M.S., December 1977, "The Analysis of Modular Design and Structured Programming in COBOL"

Hao Nhi Nham, EE, M.S., May 1978, "Design and Implementation of a Cost-Effective Digital Logic Test-Generation System"

William R. Read, EE, M.S., May 1978, "Hierarchical Methods for Generating Tests for Sequential Logic Networks in a Simulation Environment"

Ronald Lee Remke, EE, Ph.D., August 1977, "The Effects of Transition Layers Between CVD-Vanadium Dioxide Films and Oxide Substrates"

Charles Reynolds, Computer Sciences, Ph.D., August 1978, "Induction as a Basis for Understanding Computer Programs"

PERSONNEL AND RESEARCH AREAS

Advanced Degrees Awarded (cont'd)

William J. Schaffer, EE, Ph.D., December 1977, "Interfacial Silicide Formation in Nickel-Silicon Thin Film Couples"

John W. Smith, EE, M.S., August 1978, "Automated Generation of Evaluation Routines for Modular Level Simulation"

Bruce C. Walker, EE, M.S., May 1977, "An Analysis of the Design of Nonrecursive Digital Filters from Frequency Domain Specifications"

Wai-Fan Wong, EE, M.S., August 1978, "Quadratically Nonlinear Least-Mean-Square Filter"

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PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

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L.P. Devroye and G.L. Wise, "On the Recovery of Discrete Probability Densities from Imperfect Measurements," to appear in Journal of the Franklin Institute.

Luc P. Devroye and T.J. Wagner, "On the L_1 Convergence of Kernel Density Estimates," to appear in the Annals of Statistics.

Luc P. Devroye and T.J. Wagner, "Distribution-Free Inequalities for the Deleted and Holdout Error Estimates," to appear in the IEEE Transactions on Information Theory.

* Y.C. Kim, W.F. Wong, E.J. Powers, and J.R. Roth," Extension of the Coherence Function to Quadratic Models," accepted for publication in Proc. IEEE.

* M. Fink and C. Schmiedekamp, "Precise Determination of Differential Electron Scattering Cross Sections III. The Exchange Corrections," accepted for publication by J. Chem. Phys.

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* M. Fink, C.W. Schmiedekamp, and D. Gregory, "Precise Determination of Differential Electron Scattering Cross Sections II. CH_4, CO_2 and CF_4, accepted for publication by J. Chem. Phys.

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S.I. Marcus, A.S. Willsky, and K. Hsu, "The Use of Harmonic Analysis in Suboptimal Estimator Design," accepted for publication in IEEE Transactions on Automatic Control, October 1978.

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E.W. Thompson, Y.H. Jea and S.A. Szygenda, "A Timing Analysis Algorithm in Five-Value Simulation Using a Precise Delay Model," submitted to Journal of Design Automation and Fault-Tolerant Computing.

S.H. Baek, A.A. Dougal and G. Schurger, "Refractive Indices of H_2, D_2, He, O_2 and Ne up to 2000 Atmospheres," accepted for publication in Journal of Applied Physics.

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* M.H. Proffitt and L.W. Frommhold, "Concerning the Instrumental Profile of a Double Monochromator", submitted for publication Rev. Sci. Instr.

* M.H. Proffitt and L.W. Frommhold, "Concerning the Anisotropy of the Polarizability Tensor of Pairs of Methane Molecules," submitted for publication Chem. Physics.

* G.L. Wise and S.I. Marcus, "Stochastic Stability for a Class of Systems with Multiplicative State Noise," submitted to IEEE Trans. Automatic Control.

L.P. Devroye and G.L. Wise, "Detection of Abnormal Behavior Via Nonparametric Estimation of the Support," submitted to SIAM Journal on Applied Mathematics.

* R. Remke, R.M. Walser and R.W. Bene', "Transition Layers Between CVD-VO_2 and Oxide Substrates," submitted to Thin Solid Films.

G.L. Wise and N.C. Gallagher, "A Novel Approach for the Computation of Orthonormal Polynomial Expansions," submitted to SIAM Journal on Numerical Analysis.

E.W. Thompson, "Three Different Digital Simulation Models for ROM's and RAM's, submitted to IEEE Computer Journal.

* J.W. Keto, F.K. Soley, R.E. Gleason and G.K. Walters, "Exciton Lifetime in Electron Beam Excited Condensed Phases of Argon and Xenon," submitted to J. Chem. Phys.

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G.L. Wise, "On an Inequality of Beesack," submitted to Bulletin of the American Mathematical Society.

* L.P. Devroye and G.L. Wise, "Consistency of a Sequential Nearest Neighbor Regression Function Estimate," submitted to Journal of Multivariate Analysis.

* G.L. Wise, "The Effect of a Nonlinearity on the Bandlimitedness of Contaminated Gaussian Inputs," submitted to IEEE Trans. Information Theory.

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* S.H. Baek, A.A. Dougal, and G. Schurger, "Light Scattering from Laser Produced Plasmas in High Pressure Gases," submitted to Physica.

* Y.C. Kim and E.J. Powers, "Digital Bispectral Analysis and Its Applications to Nonlinear Wave Interactions," submitted for publication.

A.B. Buckman and C. Kuo, "Excitation of Coupled-Surface-Plasmons in Structures Containing Very Thin Negative Permittivity Regions," submitted to Journal of the Optical Society of America.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

TECHNICAL PRESENTATIONS AND LECTURES

1977 Conference on Information Sciences
and Systems
Johns Hopkins University
Baltimore, Maryland
April 1, 1977

R.J. Marks II, G.L. Wise, D.G. Haldeman, and J.L. Whited, "Some Preliminary Results on Detection in Laplace Noise."

Colloquium on Decision
and Control
University of Texas at Austin
April 2, 1977

*B.F. Womack, "Design and Control of Feedback Systems via Sensitivity Theory."

Stanford University
Palo Alto, CA.
April 4, 1977

G.J. Lipovski, "The Architecture of CASSM-A Context Addressed Segment Sequential Memory."

1977 IEEE International Conference
on Plasma Science
Troy, N.Y.
May 23-25, 1977

E.J. Powers, et al., "Fluctuation Induced Particle Transport in the NASA Lewis Bumpy Torus."

*Y.C. Kim and E.J. Powers, "Experimental Determination of Harmonic Generation Coupling Coefficients Using Bispectral Analysis."

E.J. Powers, "Application of Digital Time Series Analysis Techniques to Plasma Fluctuation Diagnostics" (invited paper).

*Funded entirely or in part by the Joint Services Electronics Program.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Naval Weapons Center
China Lake, California
May 1977

Jack Turner, "Fluctuations, Instability, and Self-Organization in Oscillating Chemical Reactions."

SWEMC Symposium
Austin, Texas
May 1977

H.L. Marcus, "AES in Material Science."

International Conference on Multiphoton Processes
Rochester, N.Y.
June 6-9, 1977

*Min Ho Kang, Kang Min Chung and Michael F. Becker, "Saturation Limited Third Harmonic Generation in SF_6."

Naval Research Labs
Washington, D.C.
June 7, 1977

*R.M. Walser, "Interface Reconstructive Effects on the Recrystallization of Ion-Implanted Amorphous Layers."

IEEE Computer Society Conference on Pattern Recognition and Image Processing
Troy, N.Y.
June 6-8, 1977

T.J. Wagner and L.P. Devroye, "Distribution-Free Performance Bounds with the Resubstitution on Error Estimate."

T.J. Wagner and L.P. Devroye, "Asymptotic Properties of Hierarchical Clustering Algorithms."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Annual Meeting of the
Classification Society
Dartmouth, N.H.
June 7-9, 1977

T.J. Wagner and L.P. Devroye, "Asymptotic Properties of Clustering Methods."

Third International Congress on
Waves & Instabilities in Plasmas
Paris, France
June 27-July 1, 1977

Y.C. Kim and E.J. Powers, "Harmonic-Generation of Self-Excited Large-Amplitude Ion-Acoustic Waves."

*E.J. Powers and Y.C. Kim, "Higher-Order Digitally-Implemented Spectral-Analysis of Nonlinear Wave-Wave Interaction Data."

1977 International Communications Conference
June 1977

T.K.M. Agerwala, "Communication, Computation and Computer Architecture."

IEEE MTT Symposium
San Diego, California
June 1977

T. Itoh, "Leaky-wave Antenna and Band-reject Filter for Millimeter-wave Integrated Circuits."

Southwest Electron Spectroscopy Meeting
Texas A&M University
June 1977

H.L. Marcus, "Fracture and Fatigue as Seen by Surface Sensitive Techniques."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Max-Planck Institut fur Plasmaphysik
Garching bei Munchen, F.R. Germany
July 5, 1977

E.J. Powers, "Applications of Digital Time Series Analysis Techniques to the Diagnostic Problems of Wave and Instability Identification, Fluctuation-Induced Transport and Nonlinear Wave-Wave Interactions."

Max-Planck Institut fur Plasmaphysik
Garching bei Munchen, F.R. Germany
July 29, 1977

E.J. Powers, "Analysis and Interpretation of Soft X-ray Fluctuation Data Based on Digital Spectral Analysis."

U.S.-Japan Joint Seminar on the Glow Discharge and Its Fundamental Processes
Boulder, Colorado
July 1977

J.W. Keto, "Radiative and Kinetic Processes in Rare-Gas Discharges."

Stanford University Joint Services Electronics Program Topical Review on Semiconductor Integrated Circuits, Devices & Materials
Palo Alto, California
August 3-4, 1977

*R.M. Walser, "Interphases in Silicon Systems."

NASA Lewis Research Center
Cleveland, Ohio
August 8, 1977

E.J. Powers, "Aerospace Applications of Digital Time Series Analysis Techniques."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

40th Annual Meeting of the
Institute of Mathematical Statistics
Seattle, Washington
August 14-18, 1977

T.J. Wagner and L.P. Devroye, "The Strong Uniform Consistency of Kernel Density Estimates."

20th Midwest Symposium on Circuits
and Systems
August 15-16, 1977

*B.F. Womack and Y. Tjrandra, "A Multivalued Logic Circuit in Control Systems."

Twentieth Midwest Symposium on
Circuits and Systems
Lubbock, Texas
August 16, 1977

*L.P. Devroye and G.L. Wise, "Nonparametric Detection of Changes in System Characteristics."

R.J. Marks II, G.L. Wise, and D.G. Haldeman, "Further Results on Detection in Laplace Noise."

2nd International Symposium
on the Operator Theory of
Networks and Systems
August 17-19, 1977

*B.F. Womack and S. Azuma, "A Numerical Calculation Method for Simultaneous Ordinary Differential Equation of Higher Order by the Momentary Diagonalized Modal Property."

Workshop on "New Directions
in Thermodynamics
Aspen Center for Physics
Aspen, Colorado
August 1977

Jack Turner, "Introduction to Chemical Instabilities as Nonequilibrium Phase Transitions and Critical Phenomena."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Bell Telephone Laboratories
Murray Hills, N.J.
August 1977

T.K.M. Agerwala, "Data Base Systems: Distribution Issues."

Keynote Address
Birmingham, U.K.
September 12, 1977

G.J. Lipovski, "Some Remarks on Microcomputers and Microprocessor Systems."

University of Birmingham
Birmingham, U.K.
September 15, 1977

G.J. Lipovski, "A Reconfigurable Varistructure Array Computer."

Great Malvern RAF Research Centre
September 19, 1977

G.J. Lipovski, "A Reconfigurable Varistructure Array Computer."

University of South Wales
Swansea, Wales
September 20, 1977

G.J. Lipovski, "A Reconfigurable Varistructure Array Computer."

G.J. Lipovski, "On Virtual Memories and Micronetworks."

University of Birmingham
Birmingham, U.K.
September 21, 1977

G.J. Lipovski, "CAASM - A Context Addressed Segment Sequential Memory."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Department of Communication
Paris, France
September 23, 1977

G.J. Lipovski, "On Micronetworks and Virtual Memories."

IRIA
Paris, France
September 23, 1977

G.J. Lipovski, "A Reconfigurable Varistructure Array Computer."

15th Annual Allerton Conference on Communication, Control & Computing
Monticello, Illinois
September 28-30, 1977

*S.I. Marcus, "Optimal Finite Dimensional Recursive Estimators for Discrete-Time Stochastic Nonlinear Systems."

L.P. Devroye and G.L. Wise, "On the Estimation of Discrete Probability Densities from Noisy Measurements."

*G.L. Wise and S.I. Marcus, "Stability Results For A Class of Systems with Multiplicative State Noise."

Lectures at National Cash Register, Inc.
Wichita, Kansas
September 1977

T.K.M. Agerwala, "Software Engineering."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

EUROMICRO Symposium
Amsterdam, Holland
October 4, 1977

G.J. Lipovski and C. Hoch, "A Varistructured Stack Organization."

Conference on Thin Film Phenomena - Interfaces and Interactions
Atlanta, Georgia
October 9-14, 1977

R.M. Walser and R.W. Bene', "Membrane Effects at Silicon Interfaces."

R.W. Bene' and R.M. Walser, "A Membrane Model for Interphases."

IEEE International Symposium on Information Theory
Ithaca, N.Y.
October 10-14, 1977

*T.J. Wagner and C.S. Penrod, "Nonparametric Estimation with Local Rules."

T.J. Wagner and L.P. Devroye, "Distribution-Free Inequalities for the Deleted and Holdout Error Estimates."

U.T.-Austin Colloquium on Decision & Control
Austin, Texas
October 19, 1977

*S.I. Marcus, "Fourier Series and Estimation: An Application to Optical Phase Tracking."

Nineteenth Annual Meeting of the American Physical Society Division of Plasma Physics
Atlanta, Georgia
November 7-11, 1977

*E.J. Powers and Y.C. Kim, "Determination of Nonlinear Wave-Wave Interaction Coupling Coefficients Using Bispectral Analysis Techniques."

Y.C. Kim and E.J. Powers, "Ion Acoustic Wave Harmonic Generation in a Weakly Ionized Plasma."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Colloguium on Decision
and Control
University of Texas at Austin
Austin, Texas
November 16, 1977

G.L. Wise, "Mean Square Continuity and Nonlinearities."

1977 IEEE Conference on
Decision and Control
December 7-9, 1977

*B.F. Womack and M. Oda, "Measurement, Evaluation, and Control of Communication-and-Formation Process of Morality Concept."

1977 IEEE Conference on
Decision and Control
New Orleans, Louisiana
December 7-9, 1977

*S.I. Marcus, "Fourier Series and Estimation: An Application to Optical Phase Tracking."

*S.I. Marcus, "Optimal and Suboptimal Estimation of Mixed Rotational Observables."

1977 International Symposium on
Circuits and Systems
Phoenix, Arizona

H. Chang and J.K. Aggarwal, "Design and Simulation of Two-Dimensional Interpolated Filter Systems."

20th Midwest Symposium on
Circuits and Systems
Texas Tech University
Lubbock, Texas

M.T. Manry and J.K. Aggarwal, "Design of Two-Dimensional FIR Filters with Non-Rectangular Arrays."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

National Radio Science Meeting
Boulder, Colorado
January 9-13, 1978

Y.C. Kim and E.J. Powers, "Digital Bispectral Analysis of Plasma Fluctuation Data Associated with Nonlinear Wave-Wave Interactions."

5th Annual Conference on the Physics of Compound Semiconductor Interfaces
Los Angeles, California
January 24-26, 1978

R.W. Bene', W.J. Schaffer and R.M. Walser, "Structural Study of Thin Nickel Films on Silicon Surfaces."

Computer Science Department
Indian Inst. of Tech.
Kanpur, India
January 1978

T.K.M. Agerwala,"Microprocessors."

National Radio Science Meeting
Boulder, Colorado
January 1978

T. Itoh, "On the Spectral Domain Formulation for Microstrip Line Structures."

Decision and Control Seminar Series
University of Texas at Austin
Austin, Texas
February 1978

T.K.M. Agerwala, "Control Issues in Distributed Systems."

International Solid State Circuit Conference
San Francisco, California
February 1978

T. Itoh, "Millimeter-wave Integrated Circuits."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

81st Annual Meeting of
The Texas Academy of Sciences
Texas Tech University
Lubbock, Texas
March 11, 1978

T.K.M. Agerwala, "The Fractional Horse Power Computer."

Probability and Statistics Seminar
Department of Mathematics
University of Texas at Austin
Austin, Texas
March 14, 1978

G.L. Wise, "Nonlinear Transformation of Random Processes."

Southwest Region Spring Meeting
The Society for Computer Simulation
Fort Worth, Texas
March 17, 1978

*B.F. Womack and T.F. Henson, "Modular Digital Simulation of Dynamic Systems."

School of Computer Sciences
McGill University
March 17, 1978

T.J. Wagner, "Recent Results in Nonparametric Discrimination and Density Estimation."

Texas Systems Workshop
Dallas, Texas
March 18, 1978

*S.I. Marcus, "Finite Dimensional Nonlinear Estimation in Continuous and Discrete Time."

IBM Corporation
East Fiskhill, N.Y.
March 21, 1978

R.M. Walser, "Membrane Effects at Silicon Interphases."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Johns Hopkins University
Baltimore, Maryland
March 28, 1978

G.J. Lipovski, "Some Remarks on Multi-Microcomputer Systems - Taxonomy and Synergism."

1978 Conference on Information Sciences and Systems
Johns Hopkins University
Baltimore, Maryland
March 31, 1978

G.L. Wise, "Nonlinearities with Non-Gaussian Inputs."

Workshop on the Science of Design
Sponsored by The Naval Ocean Systems Center
U.T. at San Antonio, Texas
March 1978

T.K.M. Agerwala, "Communication Issues in Distributed Computer Systems."

American Chemical Society
175th National Meeting
Anaheim, California
March 1978

Jack Turner, "From Microphysics to Macrochemistry via Discrete Simulations."

1978 International Conference on Acoustics, Speech & Signal Processing
Tulsa, Oklahoma
April 10-12, 1978

*H. Chang and J.K. Aggarwal, "Design of Semi-causal Two-Dimensional Recursive Filters."

IEEE Computer Society Workshop on Pattern Recognition and Artificial Intelligence
Princeton
April 12-14, 1978

L. Davis, S. Johns and J.K. Aggarwal, "Texture Analysis Using Generalized Coocurrence Matrices."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

IEEE Computer Society Workshop
on Pattern Recognition and
Artificial Intelligence
(continued)

J. Roach and J.K. Aggarwal, "Computer Tracking of Three-Dimensional Objects."

IEEE Region V Annual Conference
Tulsa, Oklahoma
April 16-18, 1978

*B.F. Womack and H.W. Lo, "Synthesis of Feedback Systems with Nonlinear Uncertain Plants."

Solid State Devices, Inc.
Engineering Group
Los Angelese, California
April 19, 1978

R.W. Bene', "Schottky Barriers on Silicon Surfaces."

Target Modulated Signature Meeting
U.S. Air Force Avionics Laboratory
Wright Patterson Air Force Base, Ohio
April 20, 1978

*E.J. Powers, "Bispectral Analysis of Radar Data from Vibrating Targets."

Second American Physical Society Topical
Conference on High Temperature Plasma
Diagnostics
Santa Fe, New Mexico
March 1-3, 1978

E.J. Powers, J.Y. Hong, Y.C. Kim, J.R. Roth and W.M. Krawczonek, "A Fluctuation-Induced Transport Diagnostic Based Upon FFT Spectral Analysis."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

1978 IEEE International Conference
on Plasma Science
Monterey, California
May 15-17, 1978

*Y.C. Kim and E.J. Powers, "Application of Digital Complex Demodulation Techniques in Analyzing Nonlinear Wave Data."

J.R. Roth, W.M. Krawczonek, E.J. Powers, J.Y. Hong, and Y.C. Kim, "Functional Dependence of Radial Transport in a Toroidal Plasma Subject to Strong Radial Electric Fields."

1978 IEEE Minicourse on Modern
Plasma Diagnostics
Monterey, California
May 17-19, 1978

E.J. Powers, "Fluctuation Diagnostics Based on Digital Time Series Analysis."

1978 International Symposium on
Circuits and Systems
New York
May 17-19, 1978

*K. Hirano and J.K. Aggarwal, "Design of Two-Dimensional Recursive Digital Filters with Half-Plane Symmetry Characteristics."

Topical Meeting on Picosecond
Phenomena
Hilton Head, South Carolina
May 25, 1978

*M.F. Becker, R.M. Walser and R. Gunn, "Fast Laser Excitations in VO_2 at the Semiconducting-Metallic Phase Transitions."

IEEE Computer Society Conference on
Pattern Recognition & Image Analysis
Chicago, Illinois
June 2, 1978

L. Davis, S. Johns and J.K. Aggarwal, "Texture Analysis Using Generalized Coocurrence Matrices."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

Mt. Sinai Hospital
Detroit, MI
June 2, 1978

G.J. Lipovski, "Some Remarks on Microcomputers and Applications of Microcomputers."

IBM T.J. Watson Research Laboratory
Yorktown Heights, N.Y.
June 12, 1978

*R.M. Walser, "Recrystallization of Ion-Amorphitized Silicon."

Fifth International Multivariate Analysis Symposium
University of Pittsburgh
June 14, 1978

T.J. Wagner and L.P. Devroye, "The Strong Uniform Consistency of Kernel Density Estimates."

15th Design Automation Conference
Las Vega, Nevada
June 1978

T.K.M. Agerwala, "A Synthesis Rule for Concurrent Systems."

IEEE MTT Symposium
Ottawa, Canada
June 1978

T. Itoh, D. Ratliff and A.S. Hebert, "Generalized Spectral Domain Method for Multi-Conductor Printed Lines and Its Application to Tunable Suspended Microstrips."

T. Itoh and C. Chang, "Resonant Characteristics of Dielectric Resonators for Millimeter-wave Integrated Circuits."

T. Itoh and A.S. Hebert, "Simulation Study of Electronically Scannable Antennas and Tunable Filters Integrated in a Quasi-Planar Dielectric Waveguide."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

The University of California
at Berkeley
June 1978

T.K.M. Agerwala, "Communication Issues in Parallel Algorithms and Systems."

Sperry Univac
Blue Bell, PA.
July 31, 1978

G.J. Lipovski, "Texas Reconfigurable Array Computer."

Sperry Univac
Roseville, MN
August 15, 1978

G.J. Lipovski, "CASSM - A Context Addressed Segment Sequential Memory."

G.J. Lipovski, "Texas Reconfigurable Array Computer."

Bendix Research Labs
Detroit, MI.
August 21, 1978

G.J. Lipovski, "Texas Reconfigurable Array Computer."

Pinegree Park, CO.
Colorado State University
August 29, 1978

G.J. Lipovski, "On Conditional Moves in Control Processors."

Imperial College
London, England
August 29, 1978

* S.I. Marcus, "Finite Dimensional Nonlinear Estimation in Continuous and Discrete Time."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

1977 International Conference on
Parallel Processing
Michigan
August 1978

T.K.M. Agerwala, "Loosely Coupled vs. Tightly Coupled Processing." Panel Discussion.

T.K.M. Agerwala, "Communication in Parallel Algorithms for Boolean Matrix Multiplication."

International Conference on
The Physics of Semiconductors
Edinburgh, Scotland
September 6, 1978

*R.W. Bene', R.M. Walser and James Hu, "Relationship of Metal-Semiconductor Transition To First Compound Nucleation at the Interface of A Thin Film Transition Metal on a Silicon Substrate."

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

CONFERENCE PROCEEDINGS

R.J. Marks, G.L. Wise, D.G. Haldeman, and J.L. Whited, "Some Preliminary Results on Detection in Laplace Noise," Proceedings of the 1977 Conference on Information Sciences and Systems, The Johns Hopkins University, March 30-April 1, 1977, pp. 541-545.

G.J. Lipovski, "On Imaginary Fields, Token Transfers, and Floating Codes in Intelligent Secondary Memories," Proceedings of the Third Workshop on Computer Architecture for Non-Numeric Processing, Computer Architecture News, Vol. 6, No. 2, pp. 17-22, May 1977.

* T.K.M. Agerwala, "Communication, Computation, and Computer Architecture," Record of the 1977 International Communications Conference, Chicago, June 1977.

T.J. Wagner and L.P. Devroye, "Distribution-Free Performance Bounds with the Resubstitution Error Estimate" and "Asymptotic Properties of Hierarchical Clustering Algorithms," Proceedings of the IEEE Computer Society Conference on Pattern Recognition and Image Processing, Troy, N.Y., June 6-8, 1977.

* L.P. Devroye and G.L. Wise, "Nonparametric Detection of Changes in System Characteristics," Proceedings of the Twentieth Midwest Symposium on Circuits and Systems, Texas Tech University, August 15-16, 1977, pp. 730-734.

R.J. Marks, G.L. Wise, and D.G. Haldeman, "Further Results on Detection in Laplace Noise," Proceedings of the Twentieth Midwest Symposium on Circuits and Systems, Texas Tech University, August 15-16, 1977, pp. 735-739.

G.J. Lipovski and A. Tripathi, "A Reconfigurable Varistructured Array Processor," Proceedings of the 1977 International Conference on Parallel Processing, pp. 165-174, August 1977.

L.P. Devroye and G.L. Wise, "On the Estimation of Discrete Probability Densities from Noisy Measurements," Proceedings of the Fifteenth Annual Allerton Conference on Communications, Control, and Computing, Monticello, Illinois, pp. 211-220, September 28-30, 1977.

*Funded entirely or in part by the Joint Services Electronics Program.

PUBLICATIONS, TECHNICAL PRESENTATIONS, LECTURES AND REPORTS

* G.L. Wise and S.I. Marcus, "Stability Results for a Class of Systems with Multiplicative State Noise," Proceedings of the Fifteenth Annual Allerton Conference on Communications, Control, and Computing, Monticello, Illinois, pp. 652-660, September 28-30, 1977.

S.I. Marcus, "Optimal Finite Dimensional Recursive Estimators for Discrete-Time Stochastic Nonlinear Systems," Proceedings of the Fifteenth Annual Allerton Conference on Communication, Control, and Computing, Monticello, Illinois, pp. 52-61, September 1977.

G.J. Lipovski and C.G. Hoch, "A Varistructured Stack for Microprocessors," Proceedings of the Euromicro 3rd Symposium on Microprocessing and Microprogramming, October 3, 1977, pp. 184-192.

* B.F. Womack and V.M. Levykin, "Circular-Polar Configurations of Dynamic Multiple-Connected Subsystems," Proceedings of the IFAC Symposium on Information Control Problems in Manufacturing Technology, Tokyo, Japan, 11 pp., October 17-20, 1977.

* S.I. Marcus and R.B. Asher, "Optimal and Suboptimal Estimation of Mixed Rotational Observables," in Proceedings of the 1977 IEEE Conference on Decision and Control, New York, IEEE Press, pp. 968-971, December 1977.

* S.I. Marcus and K. Kohanbash, "Fourier Series and Estimation: An Application to Optical Phase Tracking," in Proceedings of the 1977 IEEE Conference on Decision and Control, New York, IEEE Press, pp. 215-219, December 1977.

* O. Min Ho. Kang, Kang Min Chung, and Michael F. Becker, "Saturation Limited Third Harmonic Generation in SF_6," Abstracts from the International Conference on Multiphoton Processes, Optical Society of America, Rochester, N.Y., 1977.

G.J. Lipovski, "An Organization for Optical Linkages Between Integrated Circuits," AFIPS Proc. NCC'77, Vol. 46, pp. 227-236, 1977.

G.L. Wise, "Nonlinearities with Non-Gaussian Inputs," Proc. 1978 Conference on Information Sciences and Systems," Johns Hopkins University, March 29-31, 1978.

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I. INFORMATION ELECTRONICS

INFORMATION ELECTRONICS

Research Unit IE8-1. NONLINEAR FILTERING AND ESTIMATION

Principal Investigators: Professors S.I. Marcus, T.J. Wagner and G.L. Wise

Research Associate: Dr. L.P. Devroye

Graduate Students: K. Hsu and C. Liu

A. PROGRESS: Nonlinear filtering and estimation offers the possibility of constructing systems exhibiting much better performance than conventional linear systems. For over 30 years researchers have sought effective techniques for dealing with nonlinear filters and estimators; however, seemingly insurmountable difficulties frequently arise in such problems. A completely general approach does not appear possible; and we are therefore led to the need to classify nonlinear systems in a useful fashion and then develop techniques for the individual classes. This is the approach we have followed in our research, which focuses on the modeling, analysis, and design of certain nonlinear filters and estimators. Some specific objectives of this research include the understanding of certain nonlinear filters with random inputs, the development of tractable models of nonlinear systems that are accurate and not merely mathematically convenient, the development of techniques to be used in realtime nonlinear estimation, and the detection of faults or changes in the system structure.

Results on the modeling and stability of nonlinear stochastic differential systems driven by a point process are reported in [1]. The stochastic calculus of McShane is generalized; a more general canonical extension is defined, and several desirable properties are proved. A new stochastic integral with respect to a point process is defined; this alternative integral obeys the rules of ordinary calculus. Finally, moment equations and criteria for the stochastic stability of linear systems with multiplicative Poisson impulse noise are derived.

As another approach to the stability of linear systems with multiplicative noise, we considered bilinear systems with random inputs, that is, systems of the form

$$\dot{x}(t) = [A + B(t)]\, x(t)$$

where $B(t)$ was stochastic. Our investigations of moment stability properties of the state $x(t)$ are in [2]. In our model

the stochastic nature of B(t) arose from a form of filtered Poisson noise. This form of noise provides a good model for a wide variety of phenomena such as shot noise, ELF and VLF atmospheric noises, and other sporadic events such as the noise generated by a faulty component. Most previous research in this area was either restricted to the Gaussian case and/or assumed that the noise was ergodic and relied upon an eigenvalue domination argument. Our model allowed us to consider several practical forms of noises such as random amplitude pulses occurring at random points in time, which are not necessarily Gaussian or ergodic but which have a strong intuitive appeal. We introduced the use of characteristic functionals to analyze the moment stability of systems of this type. This method is very general and offers a useful technique for the investigation of such stability properties.

Realtime recursive state estimators for certain classes of nonlinear systems in both continuous and discrete time have been derived in [3] and [4]. In [4], we show that the optimal estimators for systems described by certain Volterra series expansions or by bilinear systems with nilpotent Lie algebras are recursive and finite dimensional. Estimation for nonlinear discrete time systems with additive white Gaussian observation noise is investigated in [3]. As in continuous time, we proved that, for certain classes of systems described by finite Volterra series expansions, the optimal estimator is recursive and of finite dimension. However, as opposed to the continuous time case, the optimal discrete time estimator displays the interesting phenomenon of containing polynomials in the innovations process.

In the area of density estimation, new results on the strong uniform consistency of kernel density estimates, as well as choosing the kernel width in these estimates, were given in [5]. In nonparametric discrimination, an exponential distribution-free performance bound for the deleted error estimate with k-local rules was given in [6] which significantly improves the earlier one in [7].

Frequently, the need arises to test whether the characteristics of a system are still the same, or whether they have changed. This problem is encountered in fault detection and quality control engineering. In [8] results are presented concerning the nonparametric detection of changes in system characteristics. A stochastic system with unknown structure is considered. It is assumed that the system is in operation and that the distribution of the input does not change. A localized version of the Kolmogorov-Smirnov statistic is presented and decision error bounds are derived. This localized test offers a serious computational improvement over the traditional Kolmogorov-Smirnov test.

This has been a brief summary of the principal results achieved in our first year of effort in nonlinear filtering and estimation. Several aspects of the problems are still under investigation. Specifically, the research concerning recursive finite dimensional estimators for systems with observations in Gaussian white noise and the research into the stochastic stability of bilinear system models is being directly continued. We plan to extend some of the results we have already achieved as well as investigate some new areas.

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INFORMATION ELECTRONICS

Research Unit IE8-2. ELECTRONIC MULTI-DIMENSIONAL SIGNAL PROCESSING

Principal Investigators: Professors J.K. Aggarwal and R. Jain

Graduate Students: H. Chang, N. Huang and W. Martin

A. PROGRESS: A program of research on analysis, design and implementation of multi-dimensional digital filters is in progress at the Electronics Research Center of The University of Texas at Austin. Prior work is documented in References 11 through 14. The current and proposed research is relevant to the present and future needs of the Department of Defense and involves the efficient design of two-dimensional nonrecursive digital filters, the design and implementation of two- and multi-dimensional recursive digital filters, and the analysis and synthesis of linear shift variant digital filters. Progress has been achieved as follows.

A technique for the design of two-dimensional filters based upon rotating two-dimensional frequency responses is reported in [1]. In particular, the rotation of the frequency response of separable filters is considered, and performance of these filters is tested by a simulation program with the synthetic input. The results of the above simulations are documented in [2].

The work on phase distortion due to filtering in digital pictures has been completed and is presented in [3]. Phase distortion is important not only when the distorted pictures are processed by machine but also when a person judges the pictures. Given the amplitude spectrum of an input picture and the desired and actual frequency responses of a digital filter, the measure of phase distortion due to filtering may be calculated by the technique developed in the above paper.

A two-dimensional nonrecursive filter with impulse response in the form of a rectangular array has the disadvantage that the filtering operation becomes very slow as the size of the array increases. In order to speed up the filtering operation, a high order filter array may be optimally truncated to give a low order filter array. In general, such low order filter arrays are non-rectangular. In [4], the application of windowing to high order filters to obtain non-

rectangular array filters is presented.

Recursive filters have a definite advantage over nonrecursive filters since recursive filters generally require less computational time than nonrecursive filters. However, the design of two- and multi-dimensional recursive filters with arbitrary magnitude characteristics has been difficult due to the absence of the Fundamental Theorem of Algebra in two or more dimensions. A general technique for the design of two-dimensional semicausal recursive filters with arbitrary magnitude characteristics is developed in [5] by utilizing PLSI (planar least square inverse) polynomials of semicausal form.

Frequency transformation is an important technique for generating desired filters from available prototype filters. In two dimensions frequency responses of simple prototype filters can be shifted by replacing the z-transform variables, z_1 and z_2, by $z_1 e^{-j\theta_1}$ and $z_2 e^{-j\theta_2}$. Here θ_1 and θ_2 are suitable real constants. Based upon this property, a design technique is developed for approximating nonseparable frequency characteristics by sums and products of separable transfer functions. This approximation is called "piecewise separable" decomposition of the filter characteristic. Although the overall approximating transfer function is a complicated one, the repeated structure within the transfer function reduces this complexity. The advantage of this technique is that the difficulties associated with the nonseparable characteristic do not arise in the present technique. This is a major point in favor of the present method as compared to earlier attempts at the synthesis of filters with the nonseparable characteristic. The detailed results are documented in [6].

The papers [7] and [8] have been republished in the book edited by Mitra and Ekstrom.

The research progress as reported in the journals [1,3,4] and as presented at the conferences [2,5,6] is part of a continuing program of research on multi-dimensional signal processing at The University of Texas at Austin. In addition to the work reported above, two papers [9,10] have been accepted for publication. The present research effort on multi-dimensional signal processing will be continued.

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Research Unit IE8-3. ELECTRONIC CONTROL SYSTEMS

Principal Investigators: Professors R.H. Flake, S.I. Marcus and B.F. Womack

Graduate Students: N. Brady, S. Hamidi, K. Kohanbash and B. Walker

A. ACCOMPLISHMENTS: A research program in the field of electronic control systems has been conducted under the Joint Services Electronics Program, and there have been several major accomplishments. First, sensitivity theory was utilized to develop an approach for specific optimal system design which is relatively insensitive to variations in uncertain plant model parameters [12]. The design approach is made feasible by a computational procedure which involves partitioning and uncoupling the state and sensitivity equations into subsystems. This technique has been used in the design of example real-world systems, and it has been recently extended to special classes of discrete systems [1].

Research on state estimation for systems evolving on compact manifolds, such as the sphere, has been quite successful. High-performance recursive estimators have been developed by means of harmonic expansions and assumed density approximations[2,3]. The general approach is presented in [2]; the application to problems, such as optical phase tracking, in which the observation consists of a doubly stochastic Poisson process, is studied in [3]. Optimal finite dimensional recursive state estimators for certain other classes of nonlinear stochastic systems were derived in [4]. In addition, the modeling of nonlinear stochastic systems driven by point processes was investigated; the results, reported in [5], include a generalization of the stochastic calculus of McShane and a study of stochastic stability.

In the area of distributed parameter systems, theoretical results have been obtained on the properties of the extended multiple shooting (EMS) method for solving linear elliptic boundary value problems [13 ,6]. The approach uses Newton's method to determine the initial values on the boundary of a spatial decomposition of the problem domain, and the solutions of these initial value problems are shown to converge to the solution of the original problem.

A number of other significant studies have been completed under this research unit. Large scale dynamical systems

were investigated in [14,15,16,7]. In [7] the circular-polar configuration of dynamic multiple-connected subsystems is presented, and its properties are analyzed. New results on the stability of large scale systems are derived in [14,15,16]. Levin's Loop method for analyzing qualitative stability and equilibrium shifts resulting from disturbances for partially specified systems has been extended to transient and periodic disturbances[8]. Design techniques which utilize a multivalued logic circuit to improve control system performance have been developed[9]. The solutions of search problems in parameter space for the optimization of man-machine systems are presented in [10], and a new approach to man-machine systems which involves brain theory is investigated in [11].

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INFORMATION ELECTRONICS

Research Unit IE8-4. ELECTRONIC COMPUTER SYSTEM DESIGN AND ANALYSIS

Principal Investigators: Professors S.A. Szygenda, E.W. Thompson, T.K.M. Agerwala and G.J. Lipovski

Graduate Students: A. Bose, Y. Choed-Amphai, M. D'Abreu, Y. Jea, P. Karger, B. Lint, E. Pacas-Skewes and D. Ross

A. PROGRESS

1. Design, Simulation and Testing of Digital Systems: As LSI technology gives way to VLSI's technology, the constraining point in future development is going to be the ability to verify and test such systems. Manual design verification and test set verification for such systems will be absolutely impossible. Obviously, manual logical verification at an extremely high level is possible to a limited extent, but complete verification is out of the question.

Prototyping, which has been a commonly used method, will also become impossible for these large systems. This is particularly true when one is considering accurate timing analysis. The reason for this is that prototyping of a system often occurs in a technology other than the one that is eventually used for the system. Therefore, when the prototype is established to be working correctly, the only thing that has been verified is the logical correctness of the device, and not its timing properties.

The third method, which can be used for logical verification, timing analysis, and test set verification, is digital logic simulation. The problem is that the state of the art of digital simulation today is only adequate to process 5000 to 20,000 elements, in a reasonable manner, and these elements are normally low level Boolan gates or flip-flops.

One way to increase the capability of simulation, in order to handle VLSI, is to deal with digital logic at a more abstract level, i.e., functional level simulation. The way this is normally accomplished is by making a tradeoff between accuracy or detail analysis and the level at which the network is simulated. The more accuracy and detail that is sacrificed the higher the level at which one can simulate the network. The problem with this approach is that as the integrated circuit density becomes larger the requirements for accuracy

actually increase, not decrease. The reason for this is that problems with timing become more critical and correction of these timing problems, after fabrication, becomes more costly.

The objectives of our work have been to increase the capabilities of simulation--both simulation of a fault-free network for logic verification and timing analysis[1], and simulation of faulty networks[2,3] for the verification of test sets. These objectives include simulating large networks in a cost effective manner, while maintaining the level of accuracy required. We have made progress in three areas, in terms of approaching these objectives. The first of these is the automatic partitioning of a digital network into small combinational units which can be simulated at a higher level, with the same accuracy as would be accomplished at the gate level.

The second area is the development of algorithms and data structures to support the very accurate modeling of functional units for non-fault simulation.

The third area actually builds on the second, and that is to develop a method for fault simulation which is both cost effective for large networks and yet can accommodate the accurate functional level modes developed for non-fault simulation.

In the area of logical partitioning of a network, a theoretical base was first established.[4] We discovered that there truly were logical partitions which existed which would allow for efficient simulation at an accuracy equivalent to gate level. Work then commenced on determining an efficient implementation, which would actually accomplish the automatic partitioning of a net into such units. An experimental system[5] was developed which is indeed capable of partitioning combinational networks into the small logical packets. Each individual packet is combinational in nature with no reconvergent fanout inside the packet. At this time these packets are also constrained to being single output. In some of the test cases which were run the size of the model for a digital network was cut to one third the original number of elements, i.e., the average number of gates encompassed in a partition was three. This in itself, represents a tremendous reduction in complexity of the network being considered, as well as the amount of information needed to represent the network. In addition to the partitioning, another experimental system[6] has been under development which will then perform the actual simulation of a network consisting of an interconnection of these logical partitions. This simulation will be of an accuracy level equivalent to that achieved by simulating individual gates.

The second area being considered, is that of developing techniques for simulating at the functional level with the

minimal amount of sacrifice in accuracy. This work concentrated on being able to simulate functional modules, utilizing minimum/maximum delays and hence propagating ambiguity areas through the network. Algorithms were generated for simulation and proven to be correct. Again, an experimental system was implemented. In this system a flip-flop could be modeled with numerous timing characteristics such as setup times, minimal pulse width times, and propagational delays through the element depending upon which input changed value.

The third area is that of accurate functional level fault simulation. It was determined that the two most widely accepted techniques for fault simulation (parallel fault simulation [24] and deductive [25]) are possibly not adequate for simulating networks at the functional level while maintaining a very high degree of accuracy. A third technique was then considered. This approach is called concurrent [26] fault simulation.

The only known implementation [27] of the concurrent technique dealt with the network strictly at the gate level and was not particularly accurate. Over the past 17 months a set of algorithms were developed which allowed for fault simulation to take place, having each fault modeled with different rise and fall propagational delays, setup times, and minimal pulse width times (if appropriate). This represents a very significant advance in the state of the art of accurate fault simulation. An additional major benefit is the fact that fault simulation can take place utilizing the same functional level element evaluation routines which would be used for nonfault simulation.

A problem that has plagued concurrent fault simulation, has been that it requires large amounts of storage, (as is true of deductive). Furthermore, the amount of storage needed in a given simulation run is dynamic and unpredictable to any degree. Although future work needs to be done in this area we have developed a heuristic approach which appears to help control this phenomena. This is accomplished by the use of an indicator for each fault, to determine whether it has ever been injected into the network. Once a fault has been injected, that fault's effects must be continuously modeled until it is detected, or inaccuracies will result. However, if it is possible to determine how much storage is left at any point in time, then one can make decisions about when new faults should be injected into the network. This is exactly what was accomplished. At any time that a fault is to be inserted, the decision is first made as to whether a sufficient amount of space is available. If not, no new fault is inserted into the network. This is not a foolproof plan in that any

previously induced fault activity can continue to escalate and still saturate the available storage space. However, in the experiments that we have run this solution seems to work very effectively.

The problems with concurrent simulation are primarily those of speed and storage. It has been determined, through the analysis of the existing experimental model, that a large percent of the time for concurrent fault simulation is spent in searching fault lists. It has also been determined that what contributes to the search time and also to the storage requirements is that each individual fault effect is handled separately, if it is distinguishable from the good machine. The fact that it is handled separately is the very thing that allows for these faults to be simulated at an accuracy consistent with the non-fault functional models. However, it is also very costly in terms of space and speed. The results of this analysis will direct our future work in increasing the efficiency of concurrent simulation.

The results achieved, in the areas described in this section, are felt to be of major significance for design, testing and maintenance of digital systems. Based on these results, we plan on continuing with this effort.

2. Interconnection Techniques: The proposed work relevant to interconnection techniques has resulted in two separate themes. The use of light pipes or optical links to interconnect integrated circuits in place of pins was studied[8] and has led to a contract from the Ballistic Missile Defense Advanced Technology Center for further study. It is, therefore, being phased out. The use of a Banyan Switch in reconfigurable computers was reported[9,11,15] and has led to a grant from NSF to study the architectural properties in general, and a contract from Rome Air Development Center to study applications to communication systems. The proposed work relevant to intelligent discs has resulted in analysis of some unreported aspects of the earlier work done on the CASSM system[7,10,12,14]. This work has been directed towards networks of intelligent discs and microprocessors, and has been reported in [7].

Due to considerable funding from other agencies, these topics are not being continued under the JSEP contract.

3. Petri Nets and Parallel Systems: The use of live, safe and persistent Petri nets in the design of digital systems has been investigated. Top down and bottom up techniques for the synthesis of Petri nets have been developed. This methodology is equally applicable to hardware and software systems and especially suited to systems exhibiting concurrency. A gate level implementation of transitions allows the direct translation

of nets into circuits. The resulting circuits are speed independent. Design verification through simulation requires only 3-valued unit delay simulators, thus significantly reducing simulation problems found in conventional synchronous circuits. Moreover, the circuits have inherent fault detection capabilities. Most stuck-at faults cause all operation to cease. This is an especially useful property for circuits interfacing with weapons systems or expensive peripherals. Other advantages of this methodology accrue from the utilization of a single representation scheme at various levels of abstraction: a) use of a single simulator for design verification at any stage of the design process, b) the possibility of performing functional as well as gate level simulation using the same simulator. The above work is reported in [16, 17, 18].

Significant results have also been obtained in the area of "communication in parallel systems". Models have been developed and communication measures obtained. The importance of communication aspects has been clearly demonstrated and factors affecting the nature and complexity of communication in parallel systems identified. A design methodology which includes both computation and communication aspects has been developed. Except for the initial stages[19, 20, 21], this work has been supported primarily by a grant from the National Science Foundation[19, 20, 21, 22, 23].

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Note: The work on Petri nets and parallel systems under JSEP funding will be terminated since Professor Agerwala has accepted a position with the IBM Thomas J. Watson Research Laboratory.

INFORMATION ELECTRONICS

Research Unit IE8-5. ELECTRONIC COMPUTER SOFTWARE SYSTEMS

Principal Investigator: Professor R.T. Yeh

Graduate Students: A. Araya, S. Koch and J. Lin

A. PROGRESS: Last year it was proposed that research in this area would include considerations of Large Scale Decision Support Systems (DSS). Central to any DSS system is the large amounts of data that must be efficiently stored and accessed. This consideration obviously exists for almost all large computer applications. Therefore, as a first try toward a DSS system we have undertaken research on methodologies for data storage, handling and retrieval.

Toward this end we have considered Data Base Systems (DBS), which are software systems utilizing some data base management system (DBMS) functions as building blocks. In the past decade, the implementation and usage of DBS's have been growing at a fast pace. It is reasonable to predict that in 1985, 50% of all the software systems will be DBS's. The importance of a good DBS design methodology cannot be overstressed.

The design of a DBS includes two parts: the design of the data base and the design of the programs utilizing the data base. As is done today, both parts of the design are artistic in nature and must depend on the individual experience of designers. Such design practices often produce inefficient, inflexible and inconsistent DBS's which can potentially be disastrous to the enterprise employing them.

The design of data bases has been addressed by the researchers in the data base field. Earlier efforts were mostly concentrated on the design of physical storage structures in data bases. Recently, much work was done in the logical design area. However, no comprehensive methodology has been developed. Most of the research was aiming at solving a small portion of the design problem with some restrictive assumptions. Such research provided insight to the problems and may be useful in building a methodology later. But extensive effort is still needed to solve the problem as a whole and to develop an overall design methodology.

The design of programs in a DBS has not received much attention. This is understandable because the design of a

software system in general is much more difficult than the design of data structures. Design methodologies for software systems are just starting to be developed. With the recent advances in the software engineering area, however, we believe that it is possible to include in a DBS design methodology the techniques for DBS program design. Our research is aiming at the development of a comprehensive DBS design methodology. Compared to other research in this area, our approach has the following distinct characteristics:

1. Our methodology includes the whole process of design, from gathering requirements to physical implementation.
2. We are including the DBS program design aspect.
3. We emphasize the utilization of computer based design aids in the methodology.
4. We are applying many techniques in disciplines other than the data base area, e.g., techniques in software engineering.

DBS design is a very complex problem which cannot easily be understood and solved in one step. The hierarchical design methodology used in software engineering has been applied here to separate the design into many levels of abstraction. The designer can thus first provide an initial solution in very general terms with little regard for details in implementation. Then, at each level of the design, the initial solution is refined by introducing more details. Finally, a complete solution will be obtained in the last level. This top-down approach not only allows the designer to concentrate on a small portion of the design at a given time, but also can lead to systems with better modularity and flexibility.

In Yeh, Roussopoulos and Chang,[1] we described our multi-level approach to the DB design problem. Subsequently, we modified the process to include the design of subschemas or individual user views. Figure 1 shows the levels of our design methodology in the context of a relational system. The first step in the design is to obtain a conceptual schema of the information structure; then the conceptual schema is mapped into a relational schema. The details of physical storage structures are designed in four more levels of mapping with each level introducing more implementation decisions.

Since the levels in Figure 1 are obtained with a relational model assumption, it is interesting to know whether the same level structure can be applied to the design of other data models.

Similar "multi-level" approaches can be applied to the design of DBS programs (DBSP).

As in the DB design, there is the need to have a conceptual model representing the functional aspect of the system. This model serves as a means of communication between the users and the designer. It also serves as a blueprint for the design of the abstract machine. This level is corresponding to the conceptual schema level in the DB design. Abstract machine level describes high level operations which perform the required functions without detailed specifications of the actual implementation. It is therefore, analogous to the logical (relational/CODASYL) schema level. The concept of mock-up for DBSP design is similar to the high level DB simulation concept in the CS4 system, [Berild].[2]

It is important to note that the design of DB and the design of DBSP are closely related. Designing each part individually will create sub-optimal systems. But how can we consider both designs together? The levels we propose provide a starting point and a framework for a methodology that includes both aspects of the DBS design.

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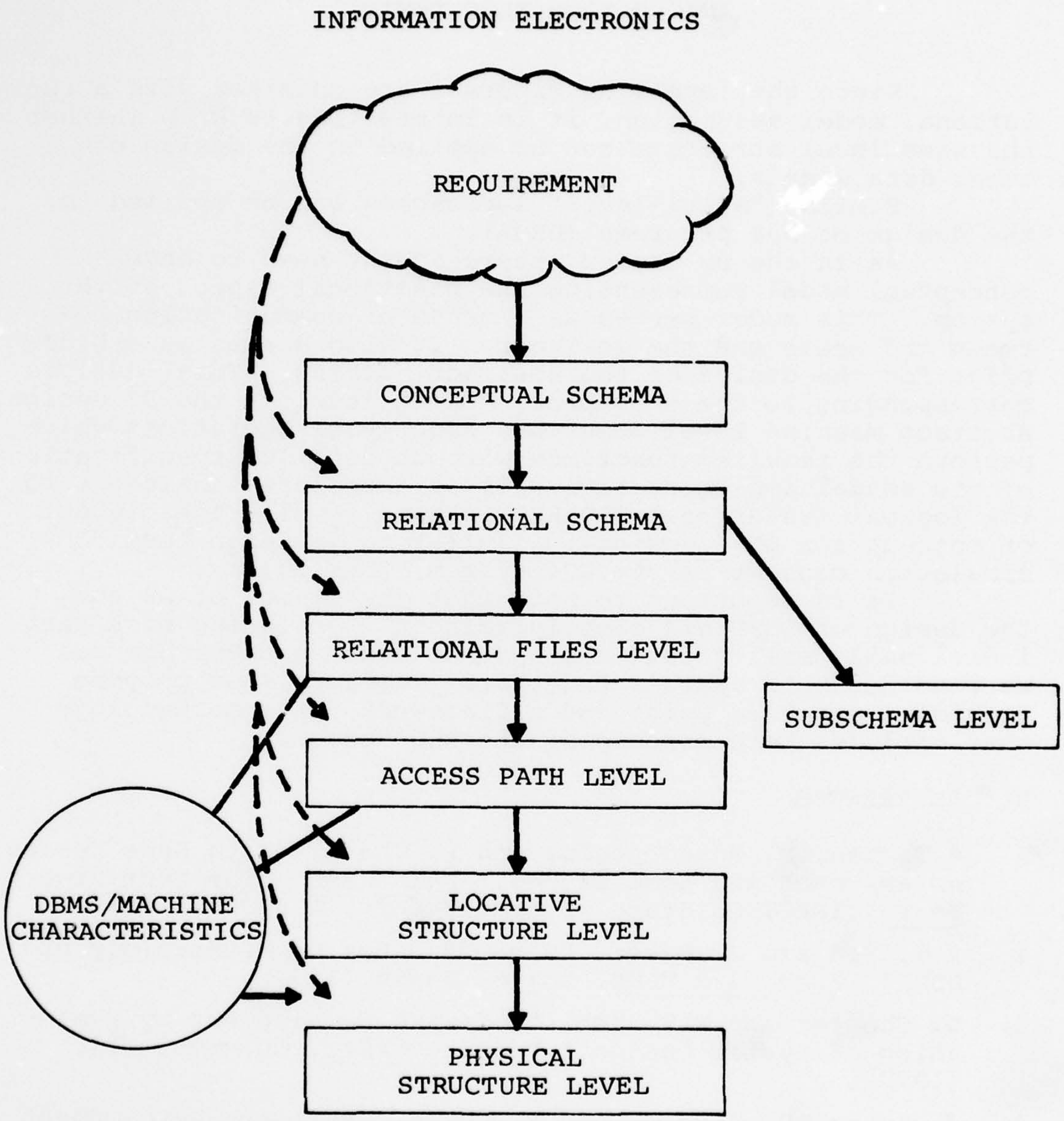

Figure 1: Multi-level data base design in relational environment.

II. SOLID STATE ELECTRONICS

SOLID STATE ELECTRONICS

Research Unit SS8-1. BASIC SOLID STATE MATERIALS RESEARCH

Principal Investigators: Professors R.W. Bené, R.M. Walser and A.B. Buckman

Graduate Students: J. Haas, C. Kuo, A. Kwok, G. Lee, J. Hu and W. Schaffer

A. PROGRESS

1. Solid State Reactions at Metal-Semiconductor Interfaces: One of our objectives in this work is to develop an understanding of the kinetically selected reaction paths and phases in the solid state reactions observed at metal-semiconductor interphases. Another objective is to relate the properties of these phases and their time development to the electronic and mechanical properties of the resultant interphase structure.

We have made some progress in our efforts to understand the basic mechanisms and physical structures involved in these low temperature reactions. We have published a model hypothesizing the formation of an intermediate "membrane" phase [1,2] which determines the crystalline phase to be nucleated and determines the height of the Schottky barriers [3]. Briefly, control of the Schottky barrier by the membrane interphase is provided by modification of the pair states which exist at the free silicon surface. To explore some of our hypotheses and to look more closely at solid phase reactions, we have made TED measurements of the structural formation of ultra thin films (10-100Å) of transition metals sputtered onto (111) and (100) Si - substrates treated in various ways. Work on a system consisting of deposited Ni on Si and SiO_2 has been published [4]. This work shows that when Ni is deposited on Si, an amorphous phase is observed for small thicknesses of Ni prior to crystallization of the Ni_2Si phase. The thickness of metal deposited before nucleation of Ni_2Si is observed at room temperature depends somewhat on the silicon substrate preparation (cleaning and backsputtering), and varies between 25Å and 40Å for different samples. Generally the samples with less than a minimum amount of backsputtering require thicker Ni deposits before Ni_2Si formation. For Ni deposition thicknesses less than about 15Å, Ni_2Si is not nucleated under any surface preparation or any subsequent annealing treatment; only the amorphous phase is observed.

When Ni is deposited on thin regions of grown SiO_2 on Si, the results depended upon the sputtering voltage and

SiO_2 thickness. Under conditions where part of the Ni is implanted through the SiO_2 layer, essentially the same results as were observed for Ni on Si were repeated except that the amount of Ni deposited before Ni_2Si nucleation was increased. For thicker layers of SiO_2 and lower sputtering voltages only rings corresponding to Ni_2SiO_4 were observed. These results seem to indicate that the onset of crystal nucleation occurs when either the glassy layer becomes thick enough at fixed concentration or else when the concentration of metal atoms reaches a critical value.

Measurements have also been made on the Co-Si substrate system where essentially the same results as for Ni were observed. In addition, for the Co-Si system, we have measured the resistivity of the thin glassy layer with different metal thicknesses as a function of temperature between 15°K and 300°K. We have found that the onset of nucleation out of the glassy phase is correlated with the two dimensional semiconductor - metal transition in that phase and have suggested a two dimensional model for the solid state nucleation process at an interface [5]. Basically, this model involves cooperatively coupling local atomic modes via a delocalizing electron system over a two dimensional interface.

Two possibilities for the coupling of local rearrangement modes over large distances are that 1) the individual electron orbitals may delocalize sufficiently for long range coupling, and 2) the electron system may undergo a phase transition to a kind of "Wigner liquid" or glass which couples to the local modes.

2. Optical Experiment Selection in Surface Studies: We have developed interactive graphics software for use in the ellipsometric determination of optical constants of a thin film with known thickness, on a known substrate. The initial tests of this software, on both "artificial" and "real" data, reveal the following characteristics:

i) The interactive plotting of constant refractive index, n, and constant absorption coefficient, k, curves for a user-specified angle of incidence reveals immediately the regions in n-k space for which the measurements will be most accurate, and for which convergence to the solution will be least dependent on initial guesses.

ii) Successive interactive plots over a range of angles of incidence allow the operator to select in minutes, a set of experimental conditions which will yield interpretable results, and which will converge for a reasonably wide range of initial guesses.

iii) With a Newton's-method solution algorithm incorporated into the program, the convergence rate as well as the convergence region can be determined.

Although this approach allows determination of a near-optimum experiment for determining the optical constants of any surface film, and shows how good such near-optimum experiment will be, our tests have to date been confined to nearly transparent films on glass substrates.

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SOLID STATE ELECTRONICS

Research Unit SS8-2. RESEARCH ON INSTABILITIES AND TRANSPORT NEAR SURFACES AND INTERFACES OF SOLIDS

Principal Investigators: Professors R.M. Walser, R.W. Bené, M.F. Becker and J.P. Stark

Graduate Students: P. Chang, M. Chonko and P. Hopkins

A. PROGRESS: The broad objective of the research described in this unit is to gain an increased understanding of the relationship between atomic rearrangements and electronic instabilities at surfaces and interfaces of solids. Our previous studies of compound nucleation and recrystallization have led to the speculation that the thermal reaction path of interfacial chemistry in solids may be determined by the fluctuations of redistributed, or delocalized, bond charge [1].

Much of our present research is motivated by the necessity of developing theoretical and experimental support for this basic initial hypothesis. We may well expect this to be a very long range goal because all aspects of this problem area are at the frontiers of solid state physics and materials science. However, because the cooperativity of these reactions results in very low critical reaction temperatures, they are of universal importance in all solid state device technologies in connection with device fabrication and stability. Accordingly, it is essential to initiate fundamental investigations of the type described.

At this time our work is aimed at 1) developing experimental techniques for producing and characterizing several model interfacial systems, 2) studying the thermally and nonthermally driven reaction kinetics of these model systems, and 3) developing theoretical models for the interfacial chemical kinetics. The following describes the specific objectives of our current research tasks and the progress made thus far.

To investigate the effects of electric fields, we are using the Pt/Si planar reaction couple. We are specifically interested in investigating the influence of electric fields on the kinetic course of the sub-eutectic silicide-forming reaction in this particular model system.

The platinum silicon system was chosen to provide a transition metal which reacts well with silicon but is not influenced by the problems of oxidation. The initial experiments were designed to determine the extent to which platinum reacts with silicon at room temperature and to determine the structure of the very thin layers of platinum as deposited.

We have found through TEM that the platinum forms an amorphous layer upon deposition up to thicknesses of 20Å is Pt_2Si.

The study of the effect of electric fields on interfacial chemical kinetics is expected to enhance our understanding of solid state electromigration and is one of our two basic studies of non-thermally excited interfacial reactions.

Theoretical progress has been made in the area of the stability of two phase dispersions subjected to an applied field such as an electric field or temperature gradient. There are several mechanisms whereby the applied field can cause diffusive flows which will perturb the two phase dispersion. The first mechanism chosen is particle dissolution to retain a saturated matrix followed by possible reprecipitation. Since the matrix phase is assumed saturated throughout the exposure to the field, end conditions are impractical. Thus, the sample is viewed as being infinite. Furthermore, to avoid the difficulties associated with coarsening during the process, the dependent variable is the volume fraction of second phase. Thus, simultaneous coarsening may occur but will be obscured by this choice of dependent variable.

For the limiting case of small volume fraction of second phase precipitates in a binary alloy, the volume fraction and the distribution function are determined for the situation where an external field gives rise to motion of the particles. In the initial analysis, particles are assumed spherical and coarsening is neglected. Further analysis for the volume fraction of such particles is possible when the migration velocity of all particles is the same.

The general equations for the distribution function using simultaneous diffusion controlled coarsening and migration of spherical particles are presented [2-5]. Solutions are obtained for situations when both particle migration and coarsening is possible.

Extensions to the complex case where end conditions can be considered necessitates the solution of two simultaneous nonlinear equations [5]. The first describes the solute continuity in a primary phase and the second describes the evolution of a precipitate phase. For small volume fractions and with the neglect of particle migration, the equations are solved for an applied electric field. The withdrawal from solute saturation at flux discontinuities is found to be a major contribution to the instability of the second phase.

We are also investigating the role of optical excitation. At present we are trying to understand optical selection rules for driving the well characterized 68°C

martensitic structural transformation in VO_2 thin films. We expect that this type of cooperative, long-range, diffusionless transition may be important at interfaces too. However, in spite of their enormous technological importance (e.g., in steelmaking) their physics is not yet well understood.

Previously we had reported on our observation that a unique non-equilibrium state could be induced in VO_2 by 41 psec and 22 nsec pulses of 1.18 eV photons at 341°K [6]. We have subsequently found that this state decays by a complex two-time constant process with the overall decay time increasing from 1 μsec to over 1 msec with increasing ambient temperature and pulse energy [7]. It is important to note that the thermal equilibrium state could not be accessed by short ($\lesssim$ 20 nsec) 1.18 eV photon pulses of any magnitude. Recently we have speculated that this result indirectly confirms recent models which view this transformation as a Fermi surface-related soft phonon mode anomaly driven by charge density excitations [8]. In our experiments, we believe this instability is preempted by fast population of alternative electronic states not related to the crystalline structure, i.e., localized states.

Finally, we have recently designed and constructed a low temperature tunneling spectrometer with which we will search for molecular-like interface electronic states that may be important to interface chemistry. We expect these to be within a few tenths eV of the Fermi level and be accessed by inelastic transitions of tunneling electrons. We are presently testing the capability of this spectrometer on metal/oxide/metal structures.

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III. QUANTUM ELECTRONICS

QUANTUM ELECTRONICS

Research Unit QE8-1. NONLINEAR WAVE PHENOMENA

Principal Investigators: Professors M.F. Becker and E.J. Powers; Dr. Y.C. Kim

Graduate Students: K. Chung, J. Hong, W. Wong and S. Zwernemann

A. PROGRESS: This unit is concerned with analytical and experimental studies of nonlinear wave phenomena in physical systems. The work is subdivided into the following two areas: (1) nonlinear optics in the infrared, and (2) development of digital time series analysis techniques suitable for analysis and interpreting fluctuation data generated by nonlinear wave interactions in various media.

Nonlinear Optics:

The objectives of this work in nonlinear optics have been to study new types of molecular nonlinearities in the infrared. We shall develop and test theories for the new nonlinearities and demonstrate, test, and optimize devices based on the newly developed theories.

Over the previous reporting period, we have continued the study of high energy, resonant excitation in SF_6[1]. The saturation of the linear and nonlinear properties of SF_6 has now been observed under various conditions but is still not well understood. In our laboratory, we have made saturated absorption and third harmonic generation measurements on pure SF_6 at low pressures where collisional effects may be ignored. We are approaching at least an empirical model of SF_6 behavior at 10.6μ as a function of pressure, laser wavelength, and incident energy density.

Preliminary third harmonic generation data has been taken on a new system, NH_3 gas. In NH_3 the triple resonance is only approximate. One photon absorption is avoided by tuning the excitation laser between discrete absorption lines. A two photon resonance is selected and is nearly exact, while the three photon resonance is detuned by as much as $10cm^{-1}$. The experiments show moderately low third harmonic conversion, as predicted by theory, due to the small population on the resonant rotational energy level at room temperature.

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We have successfully completed and submitted for publication [2] a study of third harmonic generation in metal-dielectric waveguides filled with CO as a nonlinear media. The third harmonic conversion was enhanced in the waveguide because the focused area is independent of the interaction length. For unconfined, focused laser beams these two parameters are inversely proportional and their effects cancel in the overall conversion efficiency. In our work, the theory for third harmonic generation in waveguides was developed. The conversion efficiency was calculated, based on this theory, and measured experimentally. The comparison was good considering the somewhat rough quality of the optical waveguides and of the custom cylindrical focusing optics used. Measurements were also made using unconfined, focused laser beams in order to demonstrate the enhancement provided by the waveguide configuration.

Study of SF_6 and NH_3 will continue in the coming year. Cryogenic experiments will be initiated in order to simplify and concentrate the vibrational-rotational spectra of these molecules. Much of this work, however, will be continued under the support of AFOSR-78-3712 "New Nonlinear Optical Process in Molecules at Infrared Frequencies," September 30, 1978 to September 29, 1980.

Nonlinear Wave Interactions:

The objective of this work is twofold: The first is to develop digital time series analysis techniques suitable for analyzing fluctuation data generated by nonlinear processes. The second is to develop mathematical-physical models appropriate for interpreting the results in terms of the relevant physical phenomena of interest. Classical linear spectral analysis techniques, which are based on auto- and cross-power spectra corresponding to the second moment of the time series, were discussed as a fluctuation diagnostic tool in Ref. [12] and have been successfully utilized in the study of a variety of wave phenomena. For example, the spectral indices of turbulent drift wave spectra were measured and found to be in good agreement with theory [13]. Measurements of frequency and wavelength of the electrostatic ion-cyclotron wave were made during an experimental study of wave-particle saturation [14]. By properly implementing linear spectral analysis techniques, it is feasible to study transport of charged particles across magnetic fields due to randomly fluctuating electric fields [15,16]. A recent experiment has successfully shown the usefulness of the technique [17].

Linear spectral analysis techniques are of limited value when various spectral components interact with one another due to some nonlinear or parametric process. Consequently, our most recent research has focused on utilizing higher order spectral techniques to accurately and completely characterize the fluctuating signal, since the nonlinearities result in new spectral components being formed which are phase coherent. The detection of such phase coherence may be carried out with the aid of higher order spectra. The approach utilized is based upon the least mean square analysis [18] of the fluctuation data. For example, a quadratic nonlinearity may relate three wave components in such a way that

$$X_m = A_{k,\ell} X_k X_\ell + \varepsilon$$

where X_k is the Fourier amplitude, $A_{k,\ell}$ is the coupling coefficient in a stationary situation, and the quantity ε denotes any errors associated with the imperfection of the model. Physically, the primary waves at ω_k and ω_ℓ interact and generate a third wave at their sum (or difference) frequency $\omega_m = \omega_k + \omega_\ell$.

As shown in Ref. 4, the "goodness" of the above model, which is in a quadratic regression form, may be measured by the (quadratic) correlation coefficient

$$b^2(k,\ell) = \frac{|B(k,\ell)|^2}{E\left[|X_k X_\ell|^2\right] E\left[|X_m|^2\right]}$$

We call $b(k,\ell)$ the bicoherence spectrum, since it basically measures the degree of phase coherence between three waves due to the wave coupling and is analogous to the linear coherence spectrum which measures the degree of linear correlation between two signals on a spectral basis [19]. In addition, we show in Ref. 4 that the quantity $b^2(k,\ell)P(m)$ corresponds to the power of the waves at ω_m due to the coupling of the waves at ω_k and ω_ℓ. That is, if $X_m = X_m' + A_{k,\ell} X_k X$ where X_m' is the quantity which is independent of the product interaction term, $A_{k,\ell} X_k X_\ell$, one can show

$$b^2(k,\ell)P(m) = |A_{k,\ell}|^2 E\left[|X_k X_\ell|^2\right]$$

which is the power at ω_m due to the quadratic coupling of the waves at ω_k and ω_ℓ. Note that the total power at ω_m is

$$P(m) = E\left[|X_m'|^2\right] + |A_{k,\ell}|^2 E\left[|X_k X_\ell|^2\right]$$

Therefore, $b^2(k,\ell)$ measure the fraction of power at ω_m due to the three wave coupling. As demonstrated in Refs. 8 and 9, the coupling coefficient $A_{k,\ell}$ in a stationary situation can be estimated in terms of the bispectrum. Applications of digital bispectral techniques to experimental study of nonlinear wave interactions are discussed in detail in Refs. 3,4, and 9.

We have investigated various practical aspects of digital bispectral analysis, and in Refs. 4 and 5 report on the variability of the bispectral estimators. The variances of the bispectrum estimator $\hat{B}(k,\ell)$ and the bicoherence spectrum estimator $\hat{b}(k,\ell)$, both of which are calculated from M independent records, are given by

$$\mathrm{var}\left(\hat{B}(k,\ell)\right) \approx \frac{1}{M} P(k)P(\ell)P(k+\ell)\left[1-b^2(k,\ell)\right],$$

$$\mathrm{var}\left(\hat{b}(k,\ell)\right) \approx \frac{1}{M}\left[1-b^2(k,\ell)\right]$$

where $P(k)$ is the power spectrum. The above results imply that the estimators are statistically stable when the three waves are quadratically coherent (i.e., $b^2(k,\ell)$ near unity) and relatively unstable when the waves are quadratically incoherent, (i.e., $b^2(k,\ell)$ near zero). In such incoherent cases, the variability of the estimator can be decreased by increasing the number M of realizations.

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In many experimental situations, it is often desirable to model the relationship between two (or more) physical quantities, for example, $x(t)$ and $y(t)$. During the immediate past reporting period we have concentrated on developing techniques and procedures whereby this modelling may be carried out in terms of both linear and quadratically nonlinear systems. The approach is to model the relationship either in terms of linear and quadratic impulse responses in the time domain or linear and quadratic transfer functions in the frequency domain. For a noncausal case, the frequency domain modelling is relatively straightforward. Using the results of least squares theory and multiple regression analysis, we showed in Ref. 6 that the best (in a least mean square error sense) linear and quadratic transfer functions are given by

$$L(\omega) = \frac{E[X^*(\omega)Y(\omega)]}{E[|X(\omega)|^2]} \quad , \quad Q(\omega_1,\omega_2) = \frac{E[X^*(\omega_1)X^*(\omega_2)Y(\omega)]}{E[|X(\omega_1)X(\omega_2)|^2]} \; .$$

We also demonstrated that the cross bicoherence function represents the fraction of power (or mean square value) associated with $Y(\omega)$ which can be accounted for by the quadratic nature of the model.

Contrary to the noncausal case, modelling a causal system in the frequency domain is not straightforward, since causality requires the impulse response to vanish for the time interval before the input was switched on. Modelling a quadratic causal system by a Volterra series truncated after the second-order term and utilizing an approach similar to that associated with a linear Wiener filter, we obtained [7] the following equation for the second order impulse response, $q(\tau_1,\tau_2)$,

$$\iint_0^\infty d\tau_1 d\tau_2 \; q(\tau_1,\tau_2) R_{xx}(t_1-\tau_1) R_{xx}(t_2-\tau_2) = R_{xxy}(t_1,t_2), \; t_1,t_2>0$$

which is analogous to the well-known Wiener-Hopf equation. Basically this equation relates the second order impulse response, $q(\tau_1,\tau_2)$, of the quadratic Wiener filter to R_{xx}, the auto-correlation function of the input to the filter, and R_{xxy} the cross-bicorrelation function between the input and

desired output of the filter. Employing the method of spectral factorization, we obtained the following analytic solution for the quadratic transfer function of a causal quadratic Wiener filter [5],

$$Q(\omega_1,\omega_2) = \frac{1}{(2\pi)^2\Psi_1(\omega_1)\Psi_1(\omega_2)}\iint_0^\infty d\tau_1 d\tau_2\, e^{-i\omega_1\tau_1 - i\omega_2\tau_2}$$

$$\cdot\iint_{-\infty}^{\infty} d\omega_3 d\omega_4\, e^{i\omega_3\tau_1 + i\omega_4\tau_2}\left[\frac{B_{xxy}(\omega_3,\omega_4)}{\Psi_2(\omega_3)\Psi_2(\omega_4)}\right]$$

where $B_{xxy}(\omega_1,\omega_2)$ is the cross-bispectrum and $\Psi_1(\omega)$ and $\Psi_2(\omega)$ are the factorized spectrum. It was observed [7] that the removal of the causality constraint reduced the solution to that of a noncausal system. It is important to note that for both the causal and noncausal cases, the results are valid for the class of inputs with zero third- and fourth-order cumulants.

Finally, we note that during this period we initiated a preliminary investigation to establish the feasibility of utilizing bispectral analysis of electromagnetic signals as a new signature by which various targets and emitters of radiation can be identified. This approach is motivated by an observation made in Ref. 4 where it is pointed out that it is possible for two different signals to possess identical auto-power spectra, but to exhibit different bispectra. We have carried out bispectral analysis of radar backscatter data from various vibrating metal targets (i.e., ground based vehicles) and presented preliminary results at the Target Modulated Signature meeting held at the USAF Avionics Laboratory, Wright Patterson Air Force Base [11].

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QUANTUM ELECTRONICS

Research Unit QE8-2. ATOMIC AND MOLECULAR ELECTRONIC PROCESSES

Principal Investigators: Professors L. Frommhold and M. Fink; Dr. M.H. Proffitt

Graduate Students: B. Burns, W. Eichhorn, M. Kelley, B. Miller, J. Moore and J. Turlington

A. PROGRESS:

1. Background: Atomic and molecular processes a) form the basis for the understanding of gaseous matter, and b) have important applications to high-priority technologies like lasers, energy conversion, high-altitude reactions, combustion, and electronic devices. In principle, complete theoretical answers to relevant questions lie in Schrodinger's equation and its solutions. However, rigorous solutions are known only for H. Every heavier system involving more than two particles has to be approached through approximations. Obviously, the coarseness of the approximations increase with the number of particles involved. If a very large number of particles interact simultaneously, then collective phenomena become predominant, and the solutions lie in the thermodynamic domain. Our research efforts here have been concentrated on dilute systems so that only two- and three-body interactions are important. In this research area many approximate solutions are known, but their validity and range of convergence can be judged only by comparison with experimental results. Therefore, this group is fundamentally concerned with precision measurements, although the interpretation of data repeatedly requires detailed theoretical and computational studies. The measurements performed deal with atom-atom, atom-molecule, electron-molecule, molecule-molecule, and photon-neutral cross sections over an energy range extending from 0.03 eV to 1 keV. The objectives of these measurements is the determination of the interaction potentials of the colliding systems. Due to the enormous energy range, the potentials are probed with different sensitivities at various internuclear distances. The basic technologies applied are low-energy electron scattering and Raman spectroscopy.

Low energy elastic electron scattering in the energy range of 10 eV - 1000 eV is a research tool to study the dynamic response of an atom or molecule to an incoming electron. If the electron is very slow then the induced distortion in

the charge density is adiabatic [12]. The consequences for the cross sections is a strong enhancement at small angles due to the long range dipole field which the targets produce to shield themselves from the perturbing field generated by the incoming electron. When the electron energy is increased the overall angle cross section decreases indicating a dynamic response of the molecule [13]. At very high incident energy the electron cloud is too slow to adjust to the incoming perturbation and the cross section reflects the static potential. It is the latter process we have utilized heavily and were able to exploit to such an extent that we could determine the static distribution of the electrons involved in the molecular bond forming process [14]. (This research is now supported by the NSF.) It is now our intent to extend our research to the medium and low energy range.

Electrons which interact with atoms and molecules in the 10 eV - 1000 eV energy range have a high probability of exchanging energy with the target. This process has its analog in the optical domain in the Raman spectra. The lines in the inelastic electron scattering spectrum correspond to Stokes lines, while those in the super-elastic spectrum correspond to Antistokes lines. There are two important distinctions between the two methods: The cross sections are 8 to 10 orders of magnitude different to the advantage of electron scattering; and spin flip reactions are impossible to study by optical spectroscopy. While the cross sections difference can be decreased by a couple of magnitudes by resorting to resonant Raman scattering, the second argument remains true.

The following analogies can be established:

absorption spectroscopy $\triangleq$ inelastic electron scattering

emission spectroscopy $\triangleq$ superelastic electron scattering

There are many useful relations between these spectral methods and in general it is necessary to have both spectra to resolve the molecular potential function. The same holds for the scattering processes. They are coupled through the BORN-OPPENHEIMER and the first BORN approximation. To our knowledge, the method of superelastic scattering has never been applied to molecules.

Light Scattering by Dense Gases. Whereas the scattering of light by isolated atoms and molecules (i.e., Rayleigh and Raman scattering) is well understood, scattering and attenuation by gases of atmospheric or higher density is less thoroughly known [15]. Under such conditions transient

molecular complexes, known as collisional pairs and van-der-Waals clusters, are observed, which produce an incremental photoattenuation [16]. Since complexes of this kind consist of two, three, etc., gas atoms (molecules), scattering of light by these complexes will increase roughly as the 2nd, 3rd, etc., power of the gas density and become the dominant mechanism of photoattenuation over a wide spectral range at high pressure [17]. This research attempts to measure concentrations of van-der-Waals dimers, trimers, etc., and absolute values of the light scattering incremental polarizabilities of collisional complexes, in various rare and atmospheric gases and gas mixtures. In this way, dependable photoattenuation (for non-electronic transitions) and laser beam gas heating data will be obtained. The results expected will also be useful toward a better understanding of the gas-to-liquid phase transition, particularly of its initial phases (dimerization, etc.).

2. Accomplishments: Because it was supported by JSEP for a significant fraction of the reporting period, our high energy electron scattering work will be included in this section. There are several factors which can falsify molecular structure parameters in a systematic way in the analysis of electron diffraction data. We have repeatedly reported that our counting diffraction unit produces data of unprecedented precision [1]. In order to translate this advance to structure parameters, we first had to study the integrating effect of the scattering geometry and, second, had to derive a correction function for intramolecular multiple scattering. Papers 4 and 5 report the result of the first phenomena and 2 publications are in the process of being written on the scattering theory employing a modified GLAUBER approximation.

From the scattering geometry study we learned that an old myth is wrong. The index of resolution, a fudge factor introduced in the 1950s to take care of the effect of the finite scattering volume and the residual gas scattering, is totally insufficient to do so. The other valuable result from this study was the optimum dimensions for the electron beam and the acceptance cone of the detector. With the right conditions we can collect data which is distorted significantly less by these effects than by the statistical uncertainty introduced by the counting process. The results on the intramolecular multiple scattering were no less surprising. After extending the semiclassical GLAUBER approximation to molecules we corrected our data on SF_6. The final analysis showed that all derived bond lengths remain virtually unchanged, while the values for the mean square amplitudes of vibration decreased.

This result is very pleasing because now all the structure parameters agree with spectroscopic results [18]. Since SF_6 is a prime molecule in the study of mechanisms in laser induced isotope separation our results were very welcome in this field.

In low energy electron diffraction, we are still in the build-up stage. The electron beam produced by a telefocus gun was further optimized. We need for our experiment of inelastic, elastic and superelastic scattering a very intense and very monochromatic beam. These are two conflicting requirements and we are looking at present for the optimum. The whole research effort became possible with the granting of $26,000 by The University of Texas toward the purchase of a mode-locked cavity-dumped dye laser, pumped by an 18-watt Argon ion laser. The system will cost $44,000 and will be delivered in November 1978. Since this is a totally new research area in our department, funds for auxiliary equipment up to $26,000 have been included in a departmental request to the President of The University of Texas.

Light Scattering by Dense Gases. Light of an argon ion laser is focused inside the high pressure sample cell, and the polarization selected scattered signal is observed at right angles. The J-Y double monochromater (f=1 m, aperture f/8), which features stigmatic, holographic gratings, is well suited to record the low-frequency spectra regardless of the presence of the Rayleigh line, which is typically five to six orders more intense. Absolute intensities of the collision-induced spectra, and of the Rayleigh line, are determined by direct calibration of the spectroscopic system utilizing hydrogen and nitrogen Raman lines of known intensity [8-11]. At not too high gas densities, pure two-body spectra are obtained, but with increasing gas density an increasing amount of three, four, etc., body complexes will be observed, with corresponding changes in the shape and density dependence of the observed spectra.

Hand in hand with these measurements, rigorous wave-mechanical and classical computations of the spectra are undertaken for a thorough understanding of the observations, and to obtain empirical data concerning the collision-induced, incremental polarizabilities of pairs and higher complexes. Extensive computer codes have been developed and tested, which are applicable to the case of the rare gases, or whenever isotropic interaction can be expected. Modifications will have to be incorporated when necessary to treat molecular gases.

The collision-induced binary pair spectra of the more highly polarizable gases (Ar, Kr, Xe, CH_4) were successfully recorded on an absolute intensity scale [8-11]. As a consequence, it could be shown that the anisotropy γ of the pair polarizability tensor is given by

$$\gamma(r) = 6\alpha^2 r^{-3} + k\, 6\alpha^3 r^{-6} \qquad (1)$$

for these gases. Here r designates the internuclear separation of the collisional pair, α the isolated atom polarizability and k a constant between -1 and 2. The uncertainty in k amounts to an uncertainty of the anisotropy γ of less than 4% for these gases. Equation 1 can be used to accurately compute the virial expansions of the light scattering cross sections, or extinction coefficients in these gases (and probably for most other gases, if these are as highly polarizable as Ar). This result is surprising because for many years now it has been thought that the constant k in Eq. 1 should be of the order of -50 or so, and be different for every gas. This, however, appears to be inconsistent with our experimental data [8-11].

The situation in the less polarizable gases (He^3, He^4, Ne, H_2) is unclear, at present. Spectra of helium are difficult to obtain because a) their intensities will be roughly four orders of magnitude less than those of comparable argon spectra, and b) small amounts of highly polarizable impurities may superimpose spurious spectra which interfere with the evaluation of the helium spectra. Neon and hydrogen spectra suffer similarly from the same problems, but to a lesser extent; spectra in these gases have recently been reported (we were also able to produce preliminary spectra, unpublished), but cannot be interpreted in a known way, probably because of impurities. A gas purifying system was completed here in September 1978 and will be used in the near future. Furthermore, the interfacing of a laboratory computer with our spectroscopic apparatus, which we have now completed, will allow us to obtain Raman spectra as weak as those of helium.

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Research Unit QE8-3. HIGH POWER LASER SYSTEMS

Principal Investigators: Professors J. Keto and M.F. Becker

Graduate Students: C. Hart and C. Kuo

A. PROGRESS: In this research unit two areas of research relevant to high power laser systems are being pursued. The first is the study of energy transfer processes that relate to several new gas laser systems. Second, we have initiated a study of the optical components, such as beam samplers, which are used in high power laser systems.

1. Energy Transfer Processes: The primary goal of this research has been the determination of energy transfer processes in several new lasers formed by doping rare-gases with oxides, halides, dye-vapors or metal vapors. In addition we hope to add to the fundamental understanding of the process of excitation transfer.

It has been shown that energy can be efficiently stored in excimer populations of the rare-gases. However, due to electron mixing of excimer states, lasers based on rare-gases failed to produce expected efficiencies. The idea in new systems is to efficiently transfer energy from rare-gases to dopants which have desirable lasing transitions. The approach in our laboratory is to use accurately controllable electron beam excitation (beam pulse length variable from 300 psec to C.W., beam current adjustable from 1 n.A. to 200 μ.A.) with accurate measurements of the time dependence of the fluorescence of excited states to measure kinetic processes and optical transition rates. Transitions from 2 μm to 120 nm can be observed. In addition we have high-resolution, pulsed, dye lasers available for absorption measurements. The lasers, spectrometers, and photon timing and counting electronics are interfaced to a minicomputer for data acquisition and handling. The gas sample systems use standard ultra-high vacuum techniques and are capable of pressure ranges $10T<P<40$ atm and temperature ranges $40K<T<700K$. A quadrupole mass spectrometer has been added to the chamber for monitoring of residual gases and the amount of dissociation of dopant gases during experiments.

Initial work in this laboratory has concentrated on oxide systems. Spectral surveys have been accomplished for the gas mixtures argon + N_2O, argon + O_2, and neon + O_2 over broad ranges of acceptor and dopant pressures. The purpose

of these surveys is to determine the major reaction channels and in particular to identify conditions for efficient production of $O(^1S_0)$, the state which has desirable properties for an efficient high-power amplifier. We have concluded from these surveys:

a) Large quantities of $O(^1S_0)$ have been observed in the mixtures with argon. In contrast the $O(^1S_0)$ transition in neon is very weak due to both weak production and reduced collision induced radiation.

b) In argon-oxygen mixtures the primary form of energy transfer is through charge transfer in the series of reactions

$$Ar_2^+ + O_2 \rightarrow O_2^+ + 2Ar \tag{1}$$

$$O_2^+ + e^- \rightarrow \begin{cases} O(^1S_0) + O(^3P) \\ O(^1D) + O(^3P). \end{cases} \tag{2}$$

This form of energy transfer is detrimental to lasing since dissociative recombination, shown in Eq. 2, preferentially populates the lower $O(^1D)$ state of the laser transition.

c) In neon-oxygen mixtures the major sequence of reactions is

$$Ne^* + O_2 \rightarrow (O_2^+)^* (^2\Pi_u) + Ne \tag{3}$$

$$O_2^+ (^2\Pi_u) \rightarrow O_2^+ (^2\Pi_g) + h\nu \ (\lambda = 360\ \text{nm}) \tag{4}$$

$$O_2^+(^2\Pi_u) + e^- \rightarrow \begin{cases} O + O(3^3P) \\ O + O(3^5P) \end{cases} \quad (5)$$

$$O(3^3P) \rightarrow O(3^3S) + h\nu \quad (\lambda=844.6 \text{ nm}) \quad (6)$$

$$O(3^5P) \rightarrow O(3^5S) + h\nu \quad (\lambda=777.2 \text{ nm}) \quad (7)$$

$$O(3^3S) \rightarrow O(2^3P) + h\nu \quad (\lambda=130 \text{ nm}) \quad (8)$$

It is experimentally observed that reaction 5 is preferred over reaction 3 at higher densities because of greater electron densities.

d) Though in argon the primary form of energy transfer is charge transfer, excitation transfer from rare-gas excimers does occur since the excimer bands are totally quenched for oxygen concentrations of one part in one thousand. In addition, the $O(^1S_0)$ beam current dependence is different early in the afterglow.

e) An unsymmetrical line shape and shortened lifetime for the $O(^1S_0)$ state in argon indicates the formation of ArO* excimers and collision induced radiation. For neon the transition is broadened but nearly symmetrical. Because of the weakness of the line in neon no decay rates were measured. The distinctly different sequences of reactions are different from results in glow discharges where both argon and neon produce $O(3^3P, 3^5P)$ [1].

In past experiments with neon we had been plagued with persistent N_2^+ bands. As a diagnostic to this type of problem, we have installed a UHV quadrupole mass spectrometer for residual gas analysis, identification of stable dissociation products in some mixtures, and a check of buffer gas cleanliness (sensitivity 10 ppm). After calibration and checking of this unit we have determined that the N_2 impurities are in the supplied neon gas. As a result we have constructed a gas

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cleaning system using a titanium furnace for reduction of atmospheric contaminants. In neon, other rare gases will be removed by distillation at 4K. The furnace, gas handling system, and gas sample bottles, use standard UHV practice to maintain gas purity better than 1 ppm.

Construction of the electronics, programming and final calibration of a single-photon delayed coincidence system for fast kinetic studies is completed. This system can measure fluorescence time dependences with high accuracy for decay times as short as 0.2 nsec. The first experiments using this system we are performing are detailed studies of the $(3p)^5(4p)$ states of argon. These states are produced by dissociative recombination of molecular ions and a complete understanding of their kinetics is required for planned studies of dissociative recombination in rare-gases at high pressures. Rate constants determined in time dependent studies will be compared with measurements of absolute intensities of transitions from these states as a function of pressure. Rate constants obtained with the latter technique are shown in Table 1.

Progress has been made in understanding energy transfer in electron beam excited mixtures of rare gases with dye vapors. This work is summarized in several publications [7,3,4]. In our most recent experiments, we were able to distinguish excitation of dye molecules by secondary-electrons and by excitation transfer from rare-gas excimers and excited atoms. Energy transfer is evident as a delayed population of dye molecules peaking 20 nsec in the afterglow; however, this energy is transferred too late for efficient gain production in the dye, even at buffer gas pressures of 7 atm. Electron excitation does produce intense fluorescence and recently lasing has been observed [8].

2. Laser System Components: A second objective of the research in this unit is the characterization of optical components used in high power laser systems. The grating pair or grating rhomb is frequently used as a beam sampling device for high average power lasers. Our objective is to determine analytically the inherent abberations in grating rhomb systems. An optimum or alternative configuration can then be developed. In addition, a deconvolution algorithm should be devised which can correct data already taken using an arbitrary rhomb system containing abberations.

At present we have successfully analyzed the inherent abberations in the grating rhomb beam sampler [5]. Although plane wavefronts are sampled without abberation, spherical or more complex wavefronts suffer one dimensional phase and

Table 1. Rate Constants for the Deactivation of the 4p States.

Upper Level	Lifetime [6] ($x10^{-8}$ sec $^{-1}$)	3-body ($x10^{-31}$ cm^6 sec^{-1})	2-body ($x10^{-12} cm^3 sec^{-1}$)
$4p_{3/2,2}$	3.1	1.9	7.6
$4p_{1/2,0}$	2.2	2.3	16
$4p_{5/2,3}$	2.7	1.4	13
$4p_{3/2,1}$	2.5	1.2	6.3
$4p_{5/2,2}$	3.0	2.8	9.1
$4p_{3/2,1}$	2.9	1.5	11
$4p_{1/2,1}$	2.6	2.5	2.3
$4p_{3/2,2}$	3.1	2.0	27
$4p_{1/2,0}$	2.1	9.4	6.1

displacement deviations. We have formulated an inverse filter description which employs the angular spectrum concept for the incident and sampled beams. An inverse filter is easily synthesized and may be used to deconvolute amplitude and phase data from a typical grating rhomb beam sampling system. In addition, we performed an optimization analysis in order to minimize the phase errors in the sampled beam. Some practical examples analyzed show that a phase deviation of 80 wavelengths over a curved wavefront beam can be optimized to 1/10 wavelength for the same beam. If an optimized system is used, deconvolution of the sampled beam data is seldom necessary.

QUANTUM ELECTRONICS

Analysis and improvement of the grating rhomb beam sampler will continue during the coming year in collaboration with Dr. Jerome Knopp, MIT Lincoln Laboratory. The treatment will be expanded to include input laser beams containing random phase fluctuations.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes progress on projects carried out at the Electronics Research Center at The University of Texas at Austin and which were supported by the Joint Services Electronics Program. In the area of Information Electronics progress is reported for projects involving (1) nonlinear filtering and estimation, (2) electronic multi-dimensional signal processing, (3) electronic control systems, (4) electronic computer system design and analysis and (5) electronic computer software systems.

(over)

In the Solid State Electronics area recent findings in (1) basic solid state materials research and (2) research on instabilities and transport near surfaces and interfaces of solids are described.

In the area of Quantum Electronics progress is presented for the following projects: (1) nonlinear wave phenomena, (2) atomic and molecular electronic processes and (3) high power laser systems.